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System Study of Advanced Operational Procedures for Noise Reduction

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Strategic Plan for Noise Research

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1. Executive Summary

There are three primary means for reducing airport noise: build quieter aircraft, improve the management of land use around airports, and develop noise abatement procedures. All three methodologies are important to achieving maximum noise reduction in the vicinity of airports. The development and operation of quieter aircraft is an activity led by government and industry research organizations, aircraft and engine manufacturers, and airline operators that has been ongoing for the last 30 years. Over this same time period, airport operators have worked with federal and state governments on land use initiatives directed toward reducing the noise impact on neighborhoods in the vicinity of airports. Procedural noise reduction methods, primarily using airborne noise reduction techniques, were researched in the 1970s but never brought to operational implementation on a broad scale. This research was largely abandoned in the 1980s and early 1990s in favor of the operation of quieter aircraft and improved management of land use. Many of the goals of quieter aircraft and improved land use have been achieved, but aircraft operations continue to grow and noise issues continue to plague the aviation industry. To address these problems, research is again focusing on identifying aircraft operating procedures and airspace design to reduce noise at airports.

The present study, "System Study of Advanced Operational Procedures for Noise Abatement," is aimed at defining a research program for NASA to foster the implementation of procedural noise abatement techniques on a widespread basis. There is renewed interest in this subject both in the United States (U.S.) and Europe. In Europe, the SOURDINE project (Study of Optimisation procedURes for Decreasing the Impact of NoisE around airports), initiated by The Commission of the European Communities (CEC), has involved the performance of a number of tasks for the definition and development of building blocks for a European Air Traffic Management System (EATMS). In the final report of that program (reference I), the authors state:

> "Since the entry into service of the jet transport aircraft at the end of the 1950s, the increased number of flights into and out of airports and the increased density of the urbanization have given rise to much greater intrusion of aircraft noise on community life and hence to noise exposure. Community noise is today cited as a major problem to be solved by the aircraft transport industry if its current growth is to be pursued."

This is, of course, true of the U.S., Europe and other areas of the world where high-density aircraft operations occur.

1.1 Background

There have been procedural concepts proposed since the early 1970s that showed the potential for reducing approach and departure noise. Noise abatement was the major motivating factor behind adding the wide sector coverage capability to the Microwave Landing System (MLS) concept. This capability was designed to provide precision three-dimensional (3D) area navigation capabilities during instrument approach procedures. This so-called “curved approach’ technique was intended to provide the ability to avoid noise-sensitive areas even during instrument meteorological conditions (IMC).

Another promising technique at the time was the two-segment approach procedure. This too, depended on some form of area coverage navigation capability that was accurate and reliable enough to provide 3D guidance from the high-gradient initial phase of the approach, through the transition, to the Instrument Landing System (ILS) glide slope (GS) for the final segment of the approach.

Neither of these techniques was implemented on a broad basis. MLS became involved in cost and technology development issues, preventing curved approaches from ever being operationally implemented. The two-segment procedure failed to gain acceptance due to the lack of an area-coverage navigation capability that was suitably accurate and reliable. Efforts to build quieter aircraft were showing great promise, and so efforts to further develop these procedural methods were largely discontinued.

There have been highly successful noise abatement procedures, some of which were implemented during the 1970s and 1980s. Fanning of departures (spreading noisy departures over wider areas to minimize the effects on any one area) and reduced power departures have been in use for years. The use of radar-vectored arrival and initial approach routes to avoid noise-sensitive areas is also widespread. Modifications to standard procedures for scheduling flap and landing gear deployment have been widely applied as well. These methods reduce noise by allowing throttle settings to be minimized over a longer portion of the approach course.

Improvements to engine, nacelle and airframe noise characteristics are continuing, but the major reductions to noise from these causes have already been made. Land use planning as a means of reducing noise impact on the population has proven to be a very difficult objective to implement effectively. The time has arrived to seriously investigate procedural solutions to the noise issue. The present effort concentrates on identifying the technology and operational issues that impede the implementation of procedural methods for mitigating arrival noise. Once these issues were identified and documented in the Literature Review for Task 1 (reference T), a research plan was formulated to resolve these issues and to implement noise abatement procedures. This document describes this plan.

1.2 Results

1.2.1 Noise Abatement Procedures

Based on other work being performed on procedural techniques, including ongoing work in Europe, and based on a serious review of the available documentation, a list of candidate noise abatement procedures has been compiled:

Continuous Descent Approach (CDA) – This consists of a descent procedure initiated at the latest possible point at idle throttle. The descent, in a clean aircraft configuration, is continued until the lowest altitude possible, and where a transition to a standard final approach procedure is made.

Increased GS Intercept Altitude (Extended GS) – The GS is intercepted at a point further away from the runway, enabling reduced thrust settings and higher operating altitudes during the initial part of the approach.

Increased GS Angle – The GS angle is increased above the nominal 3-degree angle and this elevated GS path is followed down to the decision height and flare for touchdown. This results in the aircraft being higher over most of the approach course.

Two-segment Approach -- An amalgam of the previous two procedures, but involving a transition to a standard GS approach for the final approach segment. This reduces noise over the initial segment of the approach. This category also includes techniques involving an abbreviated (short) final approach segment.

Reduced/Delayed Flap; Delayed Landing Configuration – An array of possible techniques for minimizing throttle settings over a greater portion of an otherwise-standard approach procedure.

Advanced Continuous Descent Approach (ACDA); Decelerating Approach – The ACDA procedure would utilize technology developments to overcome the serious capacity disadvantages of the conventional CDA procedure. The decelerating approach would implement an even greater extended GS, based on an area coverage navigation capability, and a scheduled speed reduction/flap implementation technique to minimize noise over a long portion of the approach path.

Precision Horizontal Navigation – Application of a precision navigation aid to implement procedures analogous to the MLS curved approach. This procedure allows flight paths over areas that are less sensitive to noise.

Dual Threshold Approaches – Implementation, through some means of guidance, of an otherwise-standard ILS GS approach to a displaced threshold on the runway. This would result in increased aircraft altitude over the initial and final segments.

1.2.2 Barriers to Implementation

Preventing the implementation of these procedures are a number of issues besides technology limitations. These issues can be thought of as belonging in the following categories:

Capacity, Delay and Fuel-consumption Issues - Some noise abatement procedures have serious consequences in terms of airport arrival capacity. A good example is the CDA procedure. Due to variations in performance for different makes and models of aircraft, increased inter-arrival buffers must be added which seriously impact capacity. At high-density airports, capacity, delay and fuel consumption issues may render some procedures unacceptable.

Ground System and Air Traffic Control (ATC) Controller Acceptance Issues - Some of these procedures could require a considerable investment in infrastructure support. For example, anything involving modification or addition of ILS GS transmission equipment (such as the elevated GS and displaced threshold procedures) or approach lighting systems, implies a considerable expense. Some procedures have serious impacts on airspace structure. Others may place an undue burden on the controller.

Airline and Flight Crew Acceptance Issues - The airline companies may be facing substantial investments in systems and training. Some procedures would involve development of new standards; others may involve re-certification of the aircraft for the approach procedure (the Increased GS angle procedure is an example of this issue). The airline and flight crews must have confidence in the safety aspects of the procedures. The flight crew must also be able to perform the procedure with an acceptable workload burden.

1.3 Strategic Research Plan

This plan is organized into four fundamental areas: Analysis and Design, Simulation and Refinement, Technology Development and Automation Technology Development.

These four areas are presented to form a logically cohesive plan. Only parts of this plan would be addressed and implemented by the NASA Langley Quiet Aircraft Technologies (QAT) Program, however. The general areas of interest for QAT would include Analysis and Design, and Simulation and Refinement. A possible approach by that office to selecting priority tasks from those areas, and a potential schedule of such events, are presented in section 4.3.5. The remaining areas of this plan would more appropriately be subjects of other offices within NASA, and by the Federal Aviation Administration (FAA), industry participants and international efforts.

It should be emphasized that there are more research elements presented in this plan than can be achieved given resource limitations. Also, the approach actually taken by the QAT office may coalesce several of the tasks and/or concepts into only a few individual research efforts. The concepts and research tasks are presented individually in this report for purposes of clarity.

1.3.1 Analysis and Design

The first phase of the strategic plan for procedural noise abatement research is intended to address areas amenable to study through research, analysis, computer modeling and fast-time simulation.

Aircraft Performance Modeling for Real-time ATC Decision Support Tool (DST) Applications

- Descent Performance Functions: Development of detailed functional relationships of the performance of major aircraft types during noise abatement descent and approach procedures.
- Airline Policy Modeling: Development of detailed models of airline operations preferences during descent and approach procedures.
- Runway Stopping Distance Requirements: Further development of stopping models and runway friction measurement devices to enable prediction of stopping distance by aircraft type, speed, weight and weather conditions.
- Runway Friction Monitoring Systems: Development of a systems approach to monitoring runway dampness, rate of water shedding during precipitation, and runway icing potential in order to characterize effects on braking distance.
- (Fast-time) Simulation of Descent Procedures: In support of the conduct of the above research areas, fast-time simulation efforts involving detailed aerodynamic models may be necessary to effectively characterize noise abatement procedures and to develop data pertinent to their design and evaluation.

Remote Wind Sensing Requirements

While recognizing that currently available systems may be able to meet some or all of the requirements, these tasks relate to formulating the sensing and systems requirements of such systems. Later tasks will evaluate those requirements in the light of available technologies.

- Air Mass Sensing (Ground-based): Based on requirements for tailwind component sensing out to ranges of 15 nautical miles (nm), and 3D wind detection out to a range of 2-3 nm, perform assessment of the requirements of such sensors needed to support CDA, ACDA, and reduced/delayed flap and delayed landing configuration noise abatement techniques.
- Air Mass Sensing (Airborne): Assessment of sensing requirements along the immediate forward path (1-2 nm), and at relative velocities of 120-200 knots (kts.).

Global Positioning System (GPS)/Local Area Augmentation System (LAAS)/Flight Management System (FMS) Instrument Approach/ILS Transition Design

- CDA Procedures: Since no radically new procedures or technology are required in order to develop the CDA procedure, procedure development is a relatively minor exercise.
- Two-segment Approach Procedures: Analysis and testing of standard two-segment approach procedures utilizing GPS guidance designed to intercept the ILS GS from three to seven miles out. The 'cleaner' nature of today's aircraft raises questions regarding the transition from the higher gradient to the GS gradient.
- Two-segment to Short-Final Procedures: May involve analysis, fast-time simulation, FMS algorithm development required to support the safe transition from a high-gradient descent to the GS gradient only a short distance prior to reaching decision height. Given

that these studies result in the conclusion that such procedures are safe and feasible, plans for real-time simulation studies of the concepts developed will be formulated.

- Lateral Navigation to Short-final Procedures: Building on MLS curved approach research, perform analysis, Flight Control System (FCS) and FMS development required to support the lateral navigation to short-final procedure.
- Increased GS Angle Approach Procedures: Explore airframe certification limits and analyze the potential for increased GS angle approaches based on GPS/LAAS as a sole-means precision approach system.
- FMS Developments for CDA and ACDA: FMS development work will be required to accommodate these procedures, particularly in the ACDA case. Choosing the optimum descent initiation point based on accurate navigation and wind information is important to obtaining the greatest runway capacity from the concept. Detailed development of such algorithms will set the stage for later real-time simulation studies.

Final Approach Path Monitoring Requirements

Independent flight progress monitoring systems (ground-based) may be required for the two-segment to short-final procedure and for the lateral navigation to short-final procedure.

Airspace Design and Benefit Prediction Tools

- Noise Benefit Impact Model: Involving development of a model designed to assess the noise benefit to be expected upon implementing a specific noise abatement procedure, or combination of such procedures at an actual terminal area.
- Airspace Route Modification Tool: Develop a tool, which allows airport operators and airspace planners to interactively plan modifications to terminal route structures, while providing immediate feedback of the noise implications at each step of the design.
- Real-time Airspace Configuration Tool: A logical derivative of the aforementioned tools would be a real-time terminal configuration tool which would determine the noise-optimal terminal route configuration as a function of prevailing wind, traffic demand level, time of day, closed runways, inoperative landing systems and/or communications equipment, etc.

Decision Support Tools/Automation Issues Characterization

This effort would develop the requirements for ATC automation enhancements (such as DSTs) that will be needed to support CDA and ACDA procedures. The intent is to characterize the anticipated automation capabilities so that they can be factored into the design of avionics algorithms and eventually, into the models supporting the real-time simulation studies.

1.3.2 Simulation and Refinement

This phase of the strategic plan for procedural noise abatement research groups together the research activities centering on real-time simulation. Activities included here are simulation study planning, real-time simulation studies, reevaluation of underlying procedures, technologies, algorithms and design, and generation of outputs such as piloting procedures and training recommendations, ATC data requirements and controller procedures, avionics algorithm definitions, and recommendations for avionics standards development.

GPS/LAAS/FMS Instrument Approach/ILS Transition Simulations

This is a very large category of simulation research efforts because it includes many issues, as follows:

- GPS/LAAS-based Precision Approach Development (Category (CAT) I and beyond): Subjects include piloting issues, FMS/FCS issues, assurance and redundancy issues as they apply to GPS-based Cat I approaches with and without underlying ILS (sole means), and to higher category approaches.
- Two-segment Approach Procedures: Piloting and FMS/FCS issues during standard two-segment approach procedures are subjects in this area.
- Two-segment to Short-final Procedures: The concept of conducting vertical profiles to a short stabilized segment along the standard GS brings up new issues regarding design of the FMS and FCS systems, piloting procedures, controller procedures, redundancy and cross-check requirements, flap and drag device scheduling, and wake vortex issues.
- Lateral Navigation to Short-final Procedures: The concept of conducting lateral navigation noise-abatement and time-control profiles to intercept a short final segment (three miles or less) brings up issues regarding FMS design, piloting procedures, controller procedures, redundancy and cross-check requirements.
- Increased GS Angle Procedures: Successfully implementing increased GS angle procedures brings up simulation study issues that would probably be addressed on many fronts due to the aircraft certification issues that are raised. Manufacturers and airline operators would probably be primarily involved in conducting such studies.
- ACDA FMS Issues: While the CDA approach procedure brings up few issues requiring simulator evaluation, the ACDA procedure, in attempting to precisely control descent in a very predictable way, brings up issues in aircraft performance modeling, FMS design, piloting procedures, controller procedures, and contingency procedures.

Dual/Multiple Threshold Simulation

There are few procedural or control issues associated with the availability of dual, fixed GS paths other than frequency selection and available runway length confusion issues. Given GPS/LAAS-based approaches with varying thresholds, new issues arise requiring real-time simulation: independent verification of a safe approach and landing, threshold designation, approach lighting identification and communications issues.

Final Approach Path Monitoring Simulation

During the aforementioned development efforts for determining the requirements of approach path monitoring systems, the process of developing such requirements may result in the need to utilize real-time simulation to address issues such as warning time requirements, controller awareness requirements, pilot response times, additive effects of late maneuvers with changing wind conditions, etc.

Decision Support Tools/Automation Issues Simulations

In the normal process of DST development, many alternatives regarding algorithm design will arise. These may not all be resolvable through analysis, therefore involving real-time simulation studies with the pilot and controller in the loop.

Wake Vortex Issues Simulations

As new flight regimes are introduced, such as short-final intercepts, curved approaches, two-segment (or more complex) approaches and dual/multiple thresholds, new wake vortex generation and encounter issues are introduced. The vortex encounter issue is directly addressable with real-time simulation.

Reduced/Delayed Flap Issues Simulations

The further implementation of reduced/delayed flap techniques will most likely involve real-time simulation studies. Particularly from the viewpoint of developing pilot procedures and training requirements, and verifying pilot comfort with remaining control margins, simulation studies will be a very useful tool.

1.3.3 Technology Development

This phase of the strategic plan for procedural noise abatement research examines issues of fundamental technology development that may arise as the requirements of the various subsystems become more clearly defined. These are not research areas where involvement of the QAT office would be required.

Remote Wind Sensing Technology (Ground-based)

- Air Mass Sensing (Ground-based): Tailwind component sensing out to ranges of 15 nm, and 3D (in particular, tailwind and vertical wind) detection out to a range of 2-3 nm are needed to support CDA, ACDA, and reduced/delayed flap and delayed landing configuration noise abatement techniques. Quite obviously, there are interactions with current efforts at detecting wind shear and downburst components (during final approach) that are presently in development or under deployment.
- Atmospheric Modeling: In lieu of direct sensing of tailwind and vertical wind components along the approach path, the usage of other sensors (anemometer arrays, remotely-located radar/laser devices, National Weather Service (NWS) data, etc.) with atmospheric modeling algorithms could possibly result in the derivation or prediction of the desired information.

Remote Wind Sensing Technology (Airborne)

Application of remote air mass movement sensing technologies to the airborne environment would enable advanced application of reduced/delayed flap and delayed landing configuration regardless of the existence of ground-based capability or data link.

Final Approach Path Monitoring Technology

Precision approach monitoring using the Mode S transponder and specially-designed ground antenna arrays has been under development, test and demonstration for ten years or more, with the objective of monitoring closely-spaced parallel approaches. Further development for the purpose of monitoring the two-segment to short-final procedures and lateral navigation to short-final procedures would be involved.

1.3.4 Automation Technology Development

Interactions with the Center Terminal Radar Control (TRACON) Automation System (CTAS) program are needed in specific areas to support the implementation of noise abatement procedures. Also, some of the technologies needed for noise abatement will have beneficial interactions with CTAS capabilities, which may impact CTAS development. Only minor involvement of the QAT office would be involved in these studies.

Enhancement to Final Approach Sequencing (Wind sensor data)

This research area addresses the eventual ability to use enhanced tailwind sensing capabilities for enhancing the performance of approach sequencing automation tools.

Integration of Final Approach Monitoring

Given the successful development of precision approach monitoring systems, interactions would be necessary with CTAS automation. These would involve time-critical handling of the monitor data, and uplink of emergency clearances to aircraft on final approach.

DSTs to Implement CDA Procedures & ACDA Procedures

It will be necessary to develop DSTs that will aid the controller in utilizing CDA and ACDA noise abatement techniques in a manner which will result in minimized capacity impacts.

2. History of Procedural Solutions to the Noise Abatement Problem

Throughout the history of modern commercial aviation one of the significant barriers to growth in aircraft operations is noise in the vicinity of airports. With aircraft operations in the U.S. forecast to increase by 46 percent over the next 15 years ("Forecast of IFR Aircraft Handled by FAA Air Route Traffic Control Centers FY 2000-2015."), noise at airports will continue to be an ever-increasing problem for the aviation industry and the nation as a whole.

Typically three methodologies have been applied to address airport noise issues: 1) design, manufacture, and operate aircraft with advanced technology engines and nacelle design, 2) manage the land around the airport in a manner such that land use is compatible with airport noise (e.g., land is zoned for commercial uses rather than residential), and 3) develop and apply procedural solutions to reduce noise or move flight paths away from noise sensitive areas. Over the last 30 years, all three methodologies have been successfully applied, but emphasis has been placed on quieter aircraft and improved land use. These quiet aircraft and land use noise abatement methodologies have matured to the point where further gains in noise reduction are becoming more difficult and costly to achieve. For this reason, noise researchers and operational specialists in the U.S. and Europe are increasingly looking toward improved operational procedures and airspace design to achieve further reductions in noise in the vicinity of airports.

As evidence of the renewed interest in noise reduction through changes to operational procedures, noise abatement procedures have been implemented and/or tested at a number of European cities as a part of the SOURDINE project. SOURDINE was initiated by The Commission of the European Communities. Through SOURDINE, operational noise abatement procedures have been evaluated at:

- Amsterdam, Netherlands - Schiphol Airport (Extended GS, reduced flap, and CDA procedures)
- Madrid, Spain - Barajas Airport (Increased final approach altitude with reduced flaps approach and late stabilization, CDA, and optimized take-off procedures)
- Naples, Italy - Capodichino Airport (ILS approach angle of 3.3 degrees due to terrain, continuous descent from 7,000 feet AGL, and preferential takeoff runway).

Through these evaluations, the SOURDINE project hopes to learn of the operational benefits and issues associated with the implementation of noise abatement procedures.

Operational noise abatement procedures could also be implemented at a number of cities in the United States. In order to implement these procedures effectively, procedures must be safe and reduce noise, but should not have adverse impacts on airport capacity at high-density airports. For these reasons, it is important that further research and technology development be performed to address these concerns.

2.1 Noise Research in the 1970s and 1980s

Considerable efforts were expended during the 1970s (see references A through F) in studying potential noise abatement operational procedures. The following operational procedures were studied:

- Continuous descending approaches or decelerating approaches
- Reduced/Delayed flaps or Low Power/Low Drag (LP/LD) approaches
- Increased GS angle approaches
- Two-segment approaches.

Flying various aircraft such as the BAC 1-11, Convair 990 (CV-990), Boeing 727 (B727), and selected business jets, NASA, Boeing, and the United Kingdom (UK) government tested these procedures and found that most of them would reduce noise, but not to a great enough extent to warrant changes to air traffic procedures. These various studies are summarized in Table 2.1-1.

A typical case is a test of two-segment and low-drag noise abatement procedures involving the BAC 1-11 conducted by the Royal Aircraft Establishment (RAE) (UK) in 1977:

> "…whereas the two-segment approach procedure can provide significant noise alleviation (reducing the area of highly annoyed people by up to 20%), it is much less flexible than the current low drag approach procedure and therefore more difficult to integrate into the present terminal movement area (TMA) structure (p.21, reference E)."

Another finding was that workload increased with the new procedures in the then-current air traffic system. In the case of constant descent rate approaches, it was difficult for pilots to deal with the speed changes necessary to maintain a constant descent rate while changing aircraft configuration (flaps and gear extension). For reduced flap approaches, because the aircraft were coming in on the final approach course faster, it was difficult for air traffic controllers to maintain minimum separation between succeeding aircraft. In the case of the two-segment approach, undue stress was put on the aircraft and its operating envelope, and the pilot workload was increased due to the higher speed of the approach. With system upgrades either in the aircraft or on the ground, these procedures could have been more effective in reducing noise

During the 1980s, it seems that quieter engine and nacelle technology development was the noise abatement research of choice. Testing or simulation of noise abatement operational procedures was put on hold until the 1990s. The primary exception involved the ongoing testing of the MLS, one of whose purposes was the noise-mitigation curved approach procedure.

Procedure/Study Agency	NASA (A, B, C, D)	RAE (E)	Directorate of Operational Research & Analysis (DORA) (F)
Short-term			
1--Continuous Descending	CV-990		Over 700 westerly
Approach			approaches w/ various
			aircraft at Heathrow
2—Reduced/Delayed Flaps	CV-990, B727	BAC 1-11	Over 700 westerly
(LP/LD)	GSII, JS, HS125, SL-60, LJ24		approaches w/ various
			aircraft at Heathrow
3--Increased ILS GS angle	GSII, JS, HS125, SL-60, LJ24		
Long-term			
1--Two-segmented Approach	DC-8, B-727	BAC 1-11	
	GSII, JS, HS125, SL-60, LJ24		

Table 2.1-1: 1970s Research Procedures, Agencies and Aircraft
(Lettered references are in parentheses following organization name)

2.2 Research in the 1990s

The procedures studied during the 1990s included those studied in the 1970s, but with some significant additions:

- Advanced Continuous Descent Approaches
- Dual threshold
- Increased GS intercept altitude (Extended GS)
- Precision navigation systems.

ACDA, GS extension, dual threshold, and precision navigation approaches require advancements to be made in aircraft and ground systems. Fortunately, the technology status of both types of systems has advanced impressively since the 1970s. With the advent of GPS, precision navigation is now possible. Aircraft such as the B727, B737, B747, business jets, and the McDonnell Douglas 11 (MD-11), have all been used for testing or simulating these procedures. These test programs are summarized in Table 2.2-1.

Four main studies performed in the 1990s, based on research performed in the 1970s, were accomplished by the National Aerospace Laboratory (NLR), the European Commission (SOURDINE), the Massachusetts Institute of Technology (MIT), and the Transportation Research Board (TRB). The SOURDINE study, the most comprehensive of the studies, concluded that the implementation of new operational concepts is affected by availability of new air traffic management/communication, navigation, surveillance (ATM/CNS) equipment for both ground services and aircraft. This study stated that alternative procedures must be tailored to the particular airport in which they are to be implemented. Factors such as airport operations and layout, fleet mix, ATC capabilities, geography, and regulatory restrictions, play a major role in determining the overall feasibility of a certain alternative procedure to a specific airport environment.

The MIT study showed that advanced flight guidance techniques offer the potential to reduce noise levels below the Federal Aviation Regulations (FAR) Part 36 stage III noise levels mandated by Congress. Complex maneuvers and power management strategies minimize noise exposure to the most sensitive areas.

The TRB study concluded that adopting best practices for given procedures, and choosing the best procedures for a given land use around an airport, are both likely to be capable of giving more noise benefit at less cost than further attempts to reduce source noise through new technology.

The NLR studies to date on ACDA using the B747 and the Fokker 100 indicate that substantial noise benefits could be achieved with this procedure. The research that specifically investigated the ACDA procedure found the following benefits:

1. Substantial reduction of community noise resulting from:
    - Higher altitude during a larger portion of the approach
    - Lower power settings/clean aircraft configuration
    - ATC flexibility due to curved approaches
2. Less emissions, due to the idle thrust setting
3. Fuel conservation
4. Reduction of the overall approach time.

The research efforts from both the 1970s and the 1990s conclude that more research is necessary to reduce the noise of aircraft descending into airports all over the world. This ongoing and future research is discussed further in Section 4.

Procedure/Study Agency	Committee for Aviation Environmental Protection (CAEP) (Q)	Aircraft Noise Monitoring Advisory Committee (ANMAC) (N)	Technische Univ. Delft (Netherlands) (H)	European Commission (EC) (I)	MIT (K)	National Aerospace Laboratory, Netherlands (NLR) (G, M)	NASA (P)
Short-term							
1--Continuous Descending	B747-400, B737-400	Various measured		A-320, A340	Part Task	B747-100, B737-400	B757 PC Sim.
Approach	A320, A340, MD-11			B737-400 Sim.	Simulator	MD-11 on KLM Sims.	
2—Reduce/Delayed Flaps	B747-400, B737-400	Various measured		A-320, A340		B747-100, B737-400	B757 PC Sim.
(LP/ID)	A320, A340, MD-11			B737-400 Sim.		MD-11 on KLM Sims.	
3—Extended GS	B747-400, B737-400	Various measured		A-320, A340		B747-100, B737-400	B757 PC Sim.
	A320, A340, MD-11			B737-400 Sim.		MD-11 on KLM Sims.	
4—Increased ILS GS angle						B747-100, B737-400	
						MD-11 on KLM Sims.	
Long-term							
1--Advanced Continuous Descent				A-320, A340		Various on	
Approach				B737-400 Sim.		Simulators	
2--Dual Threshold			Various on SIMMOD	A-320, A340			
				B737-400 Sim.			
3--Two-segmented Approach					Part Task		DC-8, B727
					Simulator		
4--RNAV-based SID/STAR Routing				A-320, A340			
				B737-400 Sim.			

3. Noise Abatement Issues and Procedural Solutions

3.1 Noise Abatement Issues

While several procedural solutions to the noise problem had been proposed and evaluated in the 1970s, 80s and 90s, two major barriers prevented them from being implemented. First, the level of development of airborne and ground systems technology was inadequate. Second, implementing such procedures involved modifications to the normal way of 'doing business' in terminal area operations. Numerous interactions and conflicts with normal pilot procedures, ATC procedures and airport operations issues were found to exist.

The technology issues that heretofore constrained the ability of the airborne equipment and the air traffic control system to implement these procedures now are potentially solvable. With the wide implementation of highly automated avionics systems such as advanced flight control systems and flight management systems, and given the baseline GPS capability as augmented by Wide Area Augmentation System (WAAS) and LAAS, aircraft can now potentially conduct the procedures which were envisioned (and in many cases tested) in the 1970s. Such procedures included the two-segment approach, the elevated GS-intercept approach (extended GS), the dual threshold approach, the continuous descent approach, the decelerating approach, delayed flaps, reduced flaps (LP/LD), increased GS angle, and precision horizontal guidance around noise sensitive areas. Significant strides in ATC automation have been made, and a great deal of further development is to be anticipated. Unresolved by technology at present are the means of dealing with the remaining barriers to implementation of procedural solutions to the noise problem. These include the impacts on airport capacity, fuel consumption, the functioning of the air traffic controller, the development of required avionics algorithms, and the ability of the flight crew to monitor and conduct these procedures. A final barrier to acceptance of such procedures is potential reluctance by airline management, flight crews and/or air traffic controllers to accept the procedures based on safety, reliability and workload concerns.

3.1.1 Capacity, Delay and Fuel Consumption Issues

3.1.1.1 Continuous Descent Approach

The CDA procedure involves delaying the initiation of descent to the final approach course in order to avoid flying a low-altitude level segment prior to intercepting the glide slope. The CDA procedure may be conducted by intercepting the GS from above, or by adopting a descent rate approximating the GS rate, then intercepting the course in a smooth fashion. Typically, reduced thrust (or idle thrust) is maintained throughout the descent, and it is terminated (stabilizing in final approach configuration) at the lowest possible altitude consistent with safe operation. The noise benefit arises from two causes. A benefit is realized over that portion of the descent where lower thrust values are used (up to the point of stabilization on the approach). A further benefit arises from the elimination of the low-altitude level segment prior to GS intercept. Noise impact over that terrain is reduced due to the higher operating altitude. Since initiation is late and significant thrust is not expended at lower altitudes (until stabilization), cruise fuel is consumed at the more efficient (higher) altitudes. Since descent is conducted at idle thrust and slightly more of the cruise segment is conducted at higher altitudes, the time required to arrive at the runway threshold may be slightly shorter (being variable, depending on aircraft type).

The CDA procedure does not require new airborne equipment or algorithms. The descent initiation point is readily obtainable from the descent performance chart for the aircraft type in question. With current technology, however, there is guesswork on the part of the flight crew in establishing the correct point of descent initiation due to imprecise knowledge of the headwind component through the descent. This lack of knowledge must be accounted for in order to avoid overshooting the GS profile.

There is no new automation requirement on the part of ATC. However, there is a very significant problem regarding the use of CDA procedures. The time of arrival (at the stabilization point) to be expected is very difficult for a controller to estimate. This occurs because the controller is not defining the descent initiation point. He/she cannot anticipate the expected descent performance of the various aircraft types under his control, or the way that the pilot is dealing with anticipated winds. This necessitates the addition of significant buffers between arriving aircraft, which adversely impacts capacity. The impact is so serious that this procedure has only been adopted at a few European airports, and is only currently in use at night during off-peak hours[I].

3.1.1.2 Increased GS Intercept Altitude (Extended GS)

In this procedure, the aircraft intercepts the GS profile and changes to the final approach configuration at an earlier point than is the case with conventional approaches. This causes lower thrust settings to be used outside of six miles from the decision point (normal GS intercept is between 6 and 10 miles), resulting in lower noise over that portion of the path. Also, since the level cruise segment prior to intercept is conducted at a higher altitude, noise is reduced over that segment as well. Implementing the procedure involves raising the height of other routes in the TMA, and can require restructuring the routes normally used for over flights and departing aircraft. Hence, the noise profiles of departing aircraft can be detrimentally affected as a result. This procedure is initiated under the control of ATC, and so does not have the degree of negative capacity impact associated with the CDA procedure. Workload for controllers is increased due to the requirement to monitor the aircraft further out on the final approach path. Capacity is negatively impacted (slightly) due to the need to maintain in-trail separation over a longer path. For the flight crew, a small penalty is paid due to the extended period of higher workload required to maintain the final approach descent flight path. A slight improvement in fuel consumption results.

3.1.1.3 Increased GS Angle

Conducting an ILS approach with a GS angle greater than the nominal 3-degree (5.24 percent) slope can result in lower noise, reduced fuel consumption and slightly reduced flight time. Impacts on ATC procedures are minimal. However, wake vortex avoidance is an issue that must be addressed in light of the higher descent rate, velocity and angle of attack required in conducting these approaches. Other problems from both the aircraft and ATC perspectives will make this procedure very difficult to implement. From the ATC viewpoint, a GS transmitter set at the higher angle is required (this is not only a matter of simply re-pointing the antenna array – it can involve completely revamping the ILS site preparation process). Also, it may be necessary to provide multiple antennas (and transmitting frequencies) to accommodate those aircraft which cannot safely conduct the higher-gradient approach. From the aircraft operator and pilot viewpoint, a serious issue involves the ability (and even certification) of the aircraft to conduct the transition from the higher rate of descent to flare. The higher rate of descent could also affect the decision height of the procedure, with attendant effect on Instrument Flight Rules (IFR) minimums and landing reliability under low visibility conditions. It is premature to estimate the effect on capacity without further investigation of the wake vortex avoidance issue.

3.1.1.4 Two-segment Approach

The two-segment approach procedure provides noise and fuel benefits in a manner similar to the increased GS angle procedure, but circumvents many of the serious operational and implementation issues that attend that technique. In some ways a combination of the two techniques above, the two-segment approach consists of a higher-gradient initial segment, most likely initiated at a higher altitude, that uses guidance from an area coverage navigation system. Then, a transition to the traditional 3-degree GS path is conducted while allowing sufficient time for stabilization on that path, followed by a normal transition to flare. The transition to the 3-degree GS path can be done at 2000 ft (six miles out). Of course, improved noise benefits will result if it is achieved at a lower altitude (1000 ft), resulting in an abbreviated (three miles) stabilized approach course. The serious aircraft certification and ground antenna siting problems associated with the increased GS angle procedure are avoided.

The two-segment approach has been studied extensively, particularly in the 1970s (see References A, B, D, and E). Improvements to the noise profile definitely resulted. However, certain operational problems were evident. The most significant was the lack of a suitable area coverage navigation system. Available systems were either based on Very High Frequency Omnidirectional Radio Range/Distance Measuring Equipment (VOR/DME) navigation, which was inaccurate, DME/DME navigation, which had serious coverage issues, or Loran-C navigation, which was unproven for use in such applications at the time. At present, the wide usage of GPS-based navigation, the impending implementation of WAAS and LAAS, and the maturation of very sophisticated FMS computers make this procedure a viable candidate for implementation.

These same factors are essential to the success of other advanced procedures as well, such as the ACDA procedure and the decelerating approach procedure.

The two-segment approach results in reduced noise in a manner similar to the increased GS intercept altitude case discussed above. Also, noise is reduced significantly during the initial descent segment due to the higher altitude and reduced power settings used. Noise over the foreshortened final segment is similar to the baseline case. A small fuel and time benefit also results. Capacity may be negatively impacted due to the fact that the approach speed changes at the transition between the two gradients. Wake vortex generation during the steep descent segment of the approach requires study to evaluate potential effects on arrival capacity.

3.1.1.5 Reduced/Delayed Flap; Delayed Landing Configuration

Flying the aircraft further into the approach in a clean (low drag) configuration has a positive impact on noise reduction. Lower thrust settings are used during the period of reduced drag, with lower attendant noise. Operational objections from airline personnel and flight crews stem mainly from the reduced margin for error (to accommodate unexpected wind shear, for example) which results. In the event that higher power settings are suddenly needed, long engine spool-up times cause the resulting thrust response to be significantly delayed. Flight crews also have concerns with making last-minute adjustments to the aircraft configuration a short time prior to flare. If these concerns could be belayed through improved technology and procedures, then even better noise profiles could result. Benefits are typically achieved during the level segment prior to GS intercept, and during the initial part of the final approach. Impacts on ATC procedures are minimal. Improvements to fuel economy usually result from the reduced power settings. Approach speeds are typically higher than the baseline, so there may actually be slight improvements to flight time and capacity.

3.1.1.6 Advanced Continuous Descent Approach; Decelerating Approach

These are two distinctly different procedures, but have similar noise effects overall. Both of these procedures require advanced area coverage navigation and FMS capabilities. The decelerating approach is a procedure analogous to the increased GS intercept altitude procedure, except that the GS path is intercepted even further out from the runway. Descent is conducted along a constant gradient path that is an extension of the GS path. Conducted at, or near, idle thrust, the airspeed diminishes as atmospheric density increases. Significant flap deployment doesn’t begin until six or seven miles out.

The ACDA procedure is a modification to the CDA procedure involving the use of advanced technology to mitigate the capacity disadvantage of the CDA technique. It does not involve flying down a fixed gradient path. Typically, it will involve a higher rate of descent (than the decelerating approach technique) conducted at idle thrust. The path is not fixed, but is the natural result of factors such as aircraft type, weight and ambient winds. The objective of the ACDA procedure is to be able to predict the point at which such a descent should be initiated that will result in a smooth transition to the (abbreviated) stabilized final approach path. As the descent progresses, flaps are deployed on a gradual basis, starting roughly 10 miles out, resulting in a bleed-off of airspeed. Thrust increases (and further flap deployment) occur at roughly five miles out, transitioning to a standard final approach procedure. The procedure necessarily involves the use of a precision area coverage navigation system. To increase the probability of successful implementation, accurate real-time knowledge of winds along the approach path is also required. The success of the ACDA procedure will depend on the ability of the FMS computer to calculate the descent initiation point using its knowledge of aircraft performance, 3D position and winds.

The decelerating procedure is conducted along a fixed gradient path and accommodates the winds encountered by slightly increasing thrust or through earlier deployment of flaps. Since both the decelerating procedure and the ACDA procedure are nominally conducted at idle thrust and are initiated at a higher altitude than the baseline glide path intercept, the noise benefits are similar (and substantial) in both. The noise benefit is slightly greater in the case of the ACDA procedure. Both techniques avoid the serious capacity impacts of the CDA procedure, and could be implemented during high traffic demand conditions. Both provide a degree of fuel and time savings as well.

3.1.1.7 Precision Lateral Navigation

The implementation of FMS guidance based on precision navigation information allows autonomous noise-sensitive area avoidance to be used during both arrivals and departures. This technique is introduced in detail in Appendix C – “Application of New Navigation Technology to Noise Abatement.” Coupled with real-time air/ground data link, the autonomous FMS capability can be a direct partner with the controller in cooperatively implementing conflict-free noise-avoidance paths with 4-dimensional (4D) navigation (three spatial dimensions plus arrival time control) guidance for optimizing arrival capacity. While this technique would be conceptually very attractive, bringing this concept to the point of operational implementation will involve a considerable amount of development effort in the areas of FMS algorithms and pilot procedures and man-machine interface issues. Noise-avoidance paths do not necessarily directly save fuel or time. Nor do they necessarily benefit arrival and departure capacity. Penalties can result, depending on the nature of the path involved.

3.1.1.8 Dual Threshold Approaches

Presently, the only means of implementing a dual-threshold approach is to install a second GS transmitting system at a location displaced down the runway from the primary threshold. Only after precision approach procedures based on precision 3D navigation capability (e.g. GPS with LAAS) as the sole means of guidance become approved and implemented can the dual-threshold concept be widely utilized without adding large ground system costs. Noise benefits are realized over the length of the GS path due to the slightly increased altitude. Otherwise, the approach procedure is standard. Improvements to capacity may be realized if the displaced threshold can be used to alleviate wake vortex effects on lighter aircraft following heavies. Otherwise, there would be little capacity impact.

3.1.1.9 Unified Approach Procedure

The concepts described in the above sections are presented as if they are necessarily unique, independent concepts. Given the level of automation in airborne and ATC systems achieved to date and foreseeable in the near future, this constraint is becoming obsolete. Just as ‘area navigation’, ‘aircraft performance modeling’, and ‘flight planning’ were once independent concepts, they (and many other functions) are now integrated in flight management systems. It is certainly not only plausible but advantageous to consider integrating several of these noise abatement concepts into seamless automated trajectory and configuration management algorithms implemented in advanced FMS computers. For example, integrating the ACDA, lateral navigation and reduced/delayed flaps techniques could be achieved maximizing noise benefits while eliminating capacity limitations (or even improving capacity). Development of such enhanced algorithms will probably require a considerable amount of study, real-time simulation, airline operator coordination and flight demonstration before implementation may begin.

3.1.2 Ground System and Controller Acceptance Issues

Ground system and controller acceptance issues can be thought of in terms of strategic and tactical issues. The strategic issues are those that require planning, research and investment to implement. The tactical issues are those that involve a controller’s attention in real time. These controller issues include: workload level, surrendering a degree of authority to the cockpit, sharing responsibility, maintaining situational awareness, and absorbing and interacting with increased display information content.

3.1.2.1 Continuous Descent Approach

This procedure is based on shifting responsibility for defining the point of descent initiation from the controller to the flight crew. Therefore, some traditional controller authority is surrendered in the process. This is not objectionable itself, but leaves the controller with a situation where he/she must allocate additional spacing between arrivals in order to accommodate his lack of direct control over the initiation of descent. At present, the degree of knowledge of wind conditions along the approach path that the flight crew has is lacking. Also, the controller is not in a position to predict the aircraft operating characteristics and airline policies that go into the flight deck decision. To compensate, the controller adds an additional buffer for safe spacing between arriving aircraft. The overall result is degraded arrival capacity.

Strategic improvements could be made (short of the ACDA technique) in both of these areas: better knowledge of predicted or measured winds (probably communicated to the cockpit via data link), and model-aided prediction, on the ground, of descent initiation point based on aircraft type, weight, airline policies, etc. With these improvements, the negative impact found in current CDA implementations could be somewhat reduced. This could allow CDA procedures to be implemented over more extended hours, possibly during all but the peak time period of the day.

3.1.2.2 Increased GS Intercept Altitude (Extended GS)

The major strategic issue related to the extended GS procedure is the potential need to redesign some portion of the terminal airspace. This results from the higher elevation of arrival traffic close in to the center of the terminal area, which is characteristic of this procedure. It can be a serious issue since the routes currently used for noise abatement departures may require relocation, to the detriment of their noise abatement characteristics. Where extended citizen involvement is anticipated, or when additional environmental impact studies would be required, a significant amount of investment of money and personnel time may result. In any event, such airspace changes will involve some controller training. Once the redesigned airspace and training efforts have been completed, remaining controller issues are minimal.

3.1.2.3 Increased GS Angle

While increasing the GS angle may not seriously affect the controller's day-to-day procedures, the impact on ground installation requirements for this procedure is major. The costs involved in re-siting an ILS GS installation, or in providing dual GS transmitters, are very large. The long-term solution is to utilize GPS/LAAS-based Category I and II instrument approach procedures. However, while standards development for GPS/LAAS-based CAT I and II procedures is currently under way, the certification and pilot acceptance barriers are formidable. This is not a solution that is likely to be implemented in the near term.

3.1.2.4 Two-segment Approach

Implementation of two-segment approaches will have an impact on airspace design similar to the extended GS case (section 3.1.2.2), since aircraft will intercept the approach course at a higher altitude. Similar terminal area redesign issues may result. In addition to those issues, the two-segment approach introduces a new potential wake vortex avoidance issue. Since aircraft configuration (particularly attack angle) is different during the initial high-gradient portion of the approach, wake vortex generation may be increased. This may require that new wake vortex avoidance criteria be developed specific to the situation. Thus, controllers may be dealing with a somewhat more involved set of wake vortex avoidance criteria when utilizing the two-segment procedure. On the other hand, these issues may be avoidable by assigning slightly different initial segment profiles according to aircraft type, bringing lighter aircraft in over (in stead of behind) the trailing vortices of preceding heavy aircraft.

3.1.2.5 Reduced/Delayed Flap; Delayed Landing Configuration

As stated in reference F, airlines (and the International Air Transportation Association (IATA)) have been implementing variations of these procedures to a degree since the

1970s. Speeds along the approach path that result are somewhat higher due to reduced usage of high-lift devices, but are usually very predictable. If in the final approach, flare and landing are conducted at higher speeds, some ground infrastructure changes may be needed to provide for new high speed taxiway turn-offs during high-density operations.

3.1.2.6 Advanced Continuous Descent Approach; Decelerating Approach

An accurate assessment of the effect that ACDA and decelerating approach procedures will have on the controller's planning process, and resultant ability to maintain arrival capacity at a high level, will require a significant, detailed research effort. The ACDA procedure requires improved knowledge on the flight deck of winds over the approach course (e.g. via data link). The controller requires a prediction tool that will give him/her the ability to advantageously space the arriving aircraft. This will have a significant impact on automation functionality requirements of both the cockpit avionics and air traffic control automation. Significant studies involving real-time simulations may be required to fully address these issues.

The decelerating approach procedure is conducted based on airborne navigation and flight control capabilities, and does not require significant development or investments in terms of ground facilities or ATC automation. Airspace restructuring will be required, as in the extended GS case (section 3.1.2.2). The speed profile, while somewhat faster than baseline profiles, will be predictable from aircraft to aircraft since they will be encountering similar winds. Thus, the controller should be able to maintain arrival capacity at a high level. The lengthy path over which in-trail separation must be assured may slightly limit overall arrival capacity. The overall effect on controller workload, however, is not easily determined without additional study and, possibly, real-time simulation.

3.1.2.7 Precision Navigation Capability

The precision navigation capability can enhance the design process of terminal arrival and departure routes, since precise tracking of the lateral path can be expected, and ground fixes such as VORs are not needed. Ground infrastructure effects come into play when the concept is enhanced to include procedures with short final approach segments. The short final concept involves paths where the straight-in portion may be as short as 3 miles. (This is conceptually analogous to the curved approach concept.) This procedure can result in significant noise benefits if the arrival traffic (or at least some of the traffic) can avoid noise sensitive areas while still conducting a safe instrument arrival procedure. There are several examples where this procedure is conducted visually (or with radar vectors) (e.g. the Potomac River approach to Washington, and the Canarsie approach to New York JFK). Other than requiring close attention to prevent lateral overshoots on the final approach course, this capability would not seriously impact the controller's workload. With the eventual implementation of 4D arrival time control, this concept could become part of the automated arrival spacing strategy of the future.

Significant ground infrastructure concerns come into play when these procedures are implemented in complex terminal areas. For example, if short final procedures are conducted to parallel runways, the accuracy and update rate of the surveillance radar monitoring these landings may be insufficient to guarantee time to conduct escape maneuvers when an arriving aircraft overshoots or misses the turn onto the final approach. The resulting ground system impact could be substantial.

3.1.2.8 Dual Threshold Approaches

Dual threshold approaches will affect controller training for approach, tower and ground control. The dual threshold concept could have a workload impact on controllers because the runway acceptance rate may be higher and missed approach procedures may be different depending on the threshold in use by a specific aircraft. Under present circumstances the infrastructure impact is major due to the requirement to install a second GS transmitting system at each runway where dual-threshold is to be implemented, along with requisite approach and marking lighting systems. This infrastructure impact will be considerably reduced when GPS LAAS instrument approach procedures are available.

3.1.2.9 Unified Approach Procedure

Since the unified approach procedure (introduced in section 3.1.1.9) consists of a combination or integration of two or more of the above concepts, it stands to reason that multiple ATC and ground infrastructure effects may be involved in its implementation. This is certainly true regarding controller procedures, workload and ATC automation requirements. However, since the unified procedure would be based on advanced cockpit sensors and automation, the need for major ground system investments for multiple GS transmitters, etc. would be eliminated.

3.1.3 Airline and Flight Crew Acceptance Issues

From the airline company standpoint, safety, efficiency, and investment, maintenance and training costs are important. From the flight crew viewpoint, the workload levels involved and the resulting safety of the procedures conducted on a routine basis are of paramount importance.

3.1.3.1 Continuous Descent Approach

The CDA procedure as conventionally envisioned does not involve any new avionics investment issues, but it does impose some new flight crew training requirements. It requires planning and analysis on the part of the crew to determine the proper descent initiation point. Since this activity occurs prior to the beginning of final descent, workload level during critical flight phases is not affected. However, given wind deviations from forecast, or errors in selecting the descent initiation point, an overshoot of the GS course can occur, causing a period of high workload during that critical phase of flight.

3.1.3.2 Increased GS Intercept Altitude (Extended GS)

There are no significant airline or flight crew-related issues.

3.1.3.3 Increased GS Angle

Significant airline issues arise with this technique. The most important is that many aircraft are certified for final approach operations at a GS angle not much in excess of the 3-degree standard (This is particularly true for Cat III autoland certification). Performing the analysis and flight testing required to re-certify several aircraft types would be extremely costly and, in many cases, unsuccessful. Also, there could be some very significant pilot training issues regarding the use of higher final approach gradients, particularly during the transition to flare. These factors apply regardless of whether ILS GS is used to perform the higher gradient descent or GPS/LAAS is used. In either case, transitioning from a higher descent gradient to flare can directly cause the IFR minimums associated with that procedure to be higher, resulting in lower schedule reliability which would be highly objectionable from the airline standpoint. Increasing the IFR minimums, even at the Cat I level, also increases the frequency at which IFR separations must be maintained for approaches to the runway, decreasing capacity relative to normal Visual Flight Rules (VFR) separation criteria.

3.1.3.4 Two-segment Approach

This combination of precision navigation at a high descent gradient, and a conventional procedure with ILS GS (or GPS/LAAS) during the final segment is not as difficult an issue as is the increased GS angle case (discussed in the previous section). In the two-segment case, the transition to flare is conventional, avoiding aircraft certification issues and effects on IFR minimums. The initial, high-gradient segment is conducted with the aircraft configured within its normal flight envelope. The transition to the final segment is a safety concern to airline management and flight crew alike, however. The training implications may be significant. Also, a new mode of operation must be introduced into the FMS computer. The combination of factors may require analysis through real-time simulation studies and operational demonstrations. It is anticipated that, with proper training methods, well-designed FMS modifications and operational experience, this procedure could probably gain wide acceptance.

3.1.3.5 Reduced/Delayed Flap; Delayed Landing Configuration

These procedures require no specific airline investment outside of careful development of company policies and procedures and requisite training programs. These techniques have been phased in to a certain extent over a number of years by most airlines. Further development of these procedures brings up a major issue: maintaining adequate speed, power and altitude margins to handle uncertainties (particularly wind gradients) during the final phases of the approach. It may be necessary to utilize new technologies (airborne and ground side) in order to better monitor and model wind gradients, downbursts, etc. before significant enhancements to these procedures can be implemented. Proving the viability of these techniques (and developing training methods) would also probably require additional fast-time and real-time simulation studies.

3.1.3.6 Advanced Continuous Descent Approach; Decelerating Approach

These procedures will require airline investment in the development of required avionics capabilities (GPS/LAAS systems, advanced FMS) and possibly (in the ACDA case) data link of real-time wind data. However, neither procedure raises significant safety concerns or certification issues. The ILS GS is still used for the final portion of the approach. To the flight crew the new automated procedures should not raise a workload issue, but training will be required in the operation of the new aircraft systems and in the execution of the procedure. Real-time simulation studies may be required to aid the development of FMS algorithms, operator interfaces and training requirements.

3.1.3.7 Precision Lateral Navigation Capability

Development, certification and acquisition of the precision lateral navigation capability (e.g. GPS/LAAS with FMS enhancements) will be required for implementing this capability. Training requirements will be affected. If autonomously navigated arrivals with short final approach segments are to be implemented, the effects on certification and training, and even pilot acceptance, may be substantial.

3.1.3.8 Dual Threshold Approaches

Additional training of flight crews in the operation of the 3D navigation capability supporting this technique will be required. Procedures for identifying and verifying use of the correct set of approach lights must also be developed. Those aircraft landing at the displaced threshold will be required to stop on a shorter length of runway. This is a particular problem during marginal, or deteriorating, braking conditions.

3.1.3.9 Unified Approach Procedure

Being a combination or integration of the several concepts discussed, the airline and flight crew problems noted in the previous sections would also be combined. The potential capabilities of precision four-dimensional navigation throughout the arrival, approach and flare offers significant potential for solving noise as well as capacity issues. If one considers a generalization of the instrument arrival-to-landing process, departing from conventional constraints, many possibilities arise. Two-segment approaches can become continuously decreasing gradient approaches. Sensitive area avoidance procedures can include automated velocity programming and even path stretching to achieve tightly controlled arrival times (and therefore enhanced capacity and elimination of the need for radar vectors). Wake vortex avoidance (based on real-time wind data) techniques can be included. The limitation is complexity itself. Obviously, there are numerous avionics (FMS) design, software and certification issues. The pilot interface issues are formidable as well. The flight crew must not only be able to control the desired sequence of events, but be able to monitor and anticipate problems based on the information being presented. These issues may motivate a significant requirement for detailed analysis and real-time simulation studies.

3.2 Procedural Solutions to the Noise Abatement Problem

The intent of this section is to examine the potential noise abatement payoff for each of the procedural solutions identified, to assess the implementation difficulties introduced in the previous section, and to categorize these solutions as ‘near term’, ‘intermediate term’ or ‘long term’ solutions.

Tables 3.2-1 and 3.2-2 show each of the solution areas for which research has been performed, and summarize the noise benefit of each technique and the resulting effect on each of the several areas of impact that have been discussed. Examination of the tables reveals that each of these areas has a significant potential for reducing noise if the various related problems can be overcome. The least significant noise impact predicted is for the dual-threshold approach case. Even this five percent noise reduction is significant, however. Several other approaches exhibit the potential to reduce noise from 14 percent to 28 percent. Note that while the ‘Delayed Flaps’ method only exhibits a three percent reduction, the closely related ‘Reduced Flaps’ method shows a potential for 28 percent noise reduction.

A subject of great importance is the examination of the *nature* of the noise reduction that can be achieved by each of these techniques. This is important to consider because the noise limitations that are being imposed at many airports (domestic and foreign) are usually based on some specified measurement or assessment method. In some cases noise monitor stations have been deployed. In others, the fleet mix is examined. Still others depend primarily on community reactions. These limits can be used to restrict operations for specific aircraft types, by time of day, or overall. Exactly *where* the noise benefit from a technique occurs is, therefore, of great significance. A technique that benefits one terminal area may be of little benefit to the next. Consequently, implementation of noise abatement procedures needs to be tailored to fit each specific airport, and potentially, each runway.

The areas of impact of arrival noise mitigation techniques can be broadly classified into two groups: 1) close-in (final approach segment), and 2) further out (initial/intermediate approach segment).

1) Close-in (final approach segment)

Dual Threshold Approach – By touching down at a point further down the runway, aircraft using the staggered threshold operate at a higher altitude on the intermediate and final segments, leaving a smaller noise footprint.

Reduced Flaps – While analyses have not yet shown a realistic benefit here, conducting the final segment in a cleaner configuration (at reduced thrust) should reduce noise. Of course, it is in the final segment that reductions to flap settings are most difficult to achieve.

Precision Lateral Navigation – Depending on the distance at which the final approach course intercept is achieved (and whether such short final approach procedures can be implemented), this technique may be applicable for reducing close-in noise between eight and three miles out from the runway.

Increased GS Angle – The noise reduction effect continues (but at a diminishing level of benefit) into the final approach segment using this procedure.

In summary, there are only a limited number of procedural methods for reducing noise on the final approach segment.

2) Further out (initial/intermediate approach segment)

CDA/ACDA – These techniques have a primary impact on the intermediate segment.

Delayed/Reduced Flaps – The resulting reduced thrust values affect primarily the intermediate segment.

Increased Final Approach Altitude – The extended GS procedure affects the outer areas (initial approach segment).

Increased GS Angle – Primarily impacts the intermediate approach segment.

Two-segment Approach – The effect is felt on the initial and intermediate segment only, since the standard approach course is intercepted for the final segment. Depending on the distance at which the standard GS path is intercepted, the benefit may be realized even closer to the runway.

Precision Lateral Navigation – Can be very useful for avoiding noise sensitive areas during the initial segment, and (using the short-final technique) over the intermediate segment as well.

The major noise benefits available are along the initial and intermediate approach segments. Also, the precision navigation technique can be used to control the areas impacted by arrival noise prior to final approach course intercept by steering away from noise sensitive areas.

Procedure \ Impact	Avionics required	Noise impact	Capacity impact	Delay/Sep. time
Short-term				
1--Continuous Descending Approach (CDA) MD-11, B747-100, B737-400 (G) Tested with A-230 @AMS and LHR (night) (I) Tested briefly w JetStar (Decel appch w/ 3deg GS) (A) Researched in 70s & 90s	Auto-pilot, flight director © Automatic system—deceleration (A) ILS, DME (M)	60-65decubek (dB)A CA=22% NR/27% NR (O) 65-70dBA CA=37% NR/46% NR (I, O, Q) 70-75 dBA CA=No change NR/8% NR (O) 75-80 dBA CA= 1 % noise increase (O) 80-85 dBA CA=No change NR (O) 90 dBA CA=85% NR © 9dB at 15nm out and 4dB at 9nm out (F) 5db between 10-25nm (N)	Slows down traffic due to increased spacing rqmts (G,M,N) Unpredictable approach times (I) Reduced landing capacity (i.e. application during off peak hours only) (I)	Sep. increases from 1.8 to 4 minutes due to uncertainty in approach time prediction (G,I)
2—Reduced/Delayed Flaps (LP/LD) B727 (D), CV-990 ©, MD-11, B747-400, B737-400 Implemented at AMS More beneficial if applied w/ other alternatives Research in 70s & 90s	Speed indicator, autopilot/FD, DME (D) Standard digital avionics ©	CL EPNL NR=10dB-untreated nacelles, (D) 6dB-quiet nacelles (D) 60-65dBA CA=8% NR (O) 65-70dBA CA=6% NR (O) 70-75 dBA CA=4% NR (O) 1-3dB NR 0-4 nm from threshold (F, N, Q) 1-3dB NR 0-12nm from threshold (N) 90dB CA = 9% NR ©	Doesn't significantly reduce capacity (I)	Increases runway occupancy time (N, Q)
3--Extended GS Aka Increased final approach altitude B737-400, AMS, LHR B747-400, MD-11 Researched in 90s		65dB CA = 29-33% NR (I) 55dB CA = 11% NR 2dB NR 6-12 nm from TD (I) 4-9dB from 9-15nm SEL NR-2dB/1000 ft increase in altitude @ LHR between 8-12 nm from TD (N)	Decreases capacity by 4 approaches per hour	30 second delay reduction because aircraft position is known further out; better planning
4--Increased ILS GS angle GSII, JS, HS125, SL-60, LJ24 (A) B747-400, B737-400, MD-11 Researched in 70s & 90s		55% 75dB footprint reduction (I) 3dB decrease/each deg increase in GS (I) 4 deg GS=4EPNdB NR quieter than 3deg (A)	Slight improvement due to higher Approach speeds (I)	Slightly lower delay figures (I)

Table 3.2-1: Consolidation of Approach Procedures and Impact – Short-Term
(Letters in parentheses represent reference for information from Appendix B)

Procedure \ Impact	Safe for flight crew	Acceptable to flight crew & ATC?	Fuel Impact	Approach Time Impact
Short-term				
1--Continuous Descending Approach (CDA) MD-11, B747-100, B737-400 (G) Tested with A-230 @AMS and LHR (night) (I) Tested briefly w JetStar (Decelerating appch w/ 3deg GS) (A_ Researched in 70s & 90s	Yes, pilots prefer CDA because it's smoother, more fuel efficient flight (O)	Arrival planning difficulties require increased Separation (I) Difficult for pilots to continually change speed & aircraft configuration (A, O) Difficult to make final approach separation Manageable (O)	Actual fuel savings indicated by ACMS (Aircraft Condition Monitoring System) data Analysis (I)	Due to uncertainties in the approach path to be followed, predictability of approach time is iinaccurate. (I)
2—Reduced/Delayed Flaps (LP/LD) B727(D), CV-990 ©, MD-11, B747-400, B737-400 Implemented at AMS More beneficial if applied w/ other alternatives Research in 70s & 90s	Yes w/ good avionics but needs more research (D) Diminished safety (N) Yes (M)	Approach speed is dictated by the slowest aircraft on the approach path (O) Accuracy of distance-to-go on track from initial descent to threshold; tough for ATC to provide right information at right time (C) Fast approach for pilot; less reaction time for Critical issues; ATC more flexible (I)	320 lb reduction (D)	2 minute time reduction (D)
3--Extended GS Aka Increased final approach altitude B737-400, AMS, LHR B747-400, MD-11 Researched in 90s	No direct information	Controller workload increase due to expanded approach path and (I) Monitoring of the aircraft further out (I) Earlier speed reduction required, reduced flexibility on GS	No direct information	No direct information
4--Increased ILS GS angle GSII, JS, HS125, SL-60, LJ24 (A) B747-400, B737-400, MD-11 Researched in 70s & 90s	Pilots could perceive this Procedure as unsafe (I)	Considerable resistance from ICAO (I)	Significant reduction of fuel burnt (I)	No direct information

Table 3.2-1: Consolidation of Approach Procedures and Impact – Short-Term (Continued)
(Letters in parentheses represent reference for information from Appendix B)

Procedure \ Impact	Impact on Operator Economics	Constraints/Problems to be solved	Technology still needed
Short-term			
1--Continuous Descending Approach (CDA) MD-11, B747-100, B737-400 (G) Tested with A-230 @AMS and LHR (night) (I) Tested briefly w JetStar (Decel appch w/ 3deg GS) (A) Researched in 70s & 90s	No direct information	Upgrade ATC facilities & equipment (I) Constrained by ATC tactical control including descent clearance distance & sequencing flexibility (I)	Automatic system to handle a decelerating approach (A) Improved spacing tools or approach monitoring tools (I) RNAV necessary for virtual construction of 3-degree GS (O)
2—Reduced/Delayed Flaps (LP/LD) B727 (D), CV-990 ©, MD-11, B747-400, B737-400 Implemented at AMS More beneficial if applied w/ other alternatives Research in 70s & 90s	No direct information	Need for additional pilot training & enhanced navigational aids to compensate for wind & other op'l variables to consistently hit target © Greater use of reverse thrust; increase in brake wear (Q) Need for additional pilot training & enhanced navigation aids © Key limitation: ATC speed control (O)	No direct information
3--Extended GS Aka Increased final approach altitude B737-400, AMS, LHR (I) B747-400, MD-11 Researched in 90s	No direct information	ILS must be upgraded due to signal reliability further out (I) Controller workload increase due to monitoring further out (I) PAN-OPS resistance because it's now only 3000'. If increase, then that considerably lengthens the approach path (I)	Requires upgrade to ILS to cover extended area for longer intercept (I) More reliable ILS signals & system integrity (I) Arrival manager tool = mandatory (I)
4--Increased ILS GS angle GSII, JS, HS125, SL-60, LJ24 (A) B747-400, B737-400, MD-11 Researched in 70s & 90s	Cost savings due due to fuel reduction (I)	Resistance to changing standard 3-deg GS (PAN-OPS) (M) Opposition from regulatory authorities & operational entities (ICAO standards) (I) Long campaign of flight test will be required before ICAO Approval of larger angle (I)	Change in existing a/c navigation, ATC system & procedures, & existing flight regulations (I) Accurate ILS (I)

Table 3.2-1: Consolidation of Approach Procedures and Impact – Short-Term (Continued)
(Letters in parentheses represent reference for information from Appendix B)

Procedure \ Impact	Avionics required	Noise impact	Capacity impact	Delay/Sep. time
Long-term				
1--Advanced Continuous Descent Approach B747-400, Fokker 100, B737-400 Researched in 90s	FMS, 4-D RNAV, DGPS (G, I) Planning & monitoring ATC tools (I)	Substantial NR in communities (G)	Slight reduction w/ current ATC & navigation tools but w/ right tools, could be same as current level (I)	Back to 'normal' (I)
2—Dual Threshold Trials performed at Frankfurt Researched in 90s	Accurate ILS avionics (H)	NR increased if combined w/ other procedures (I)	6% increase due to reduced separation unless there's a problem on rwy (H) Reducing final approach spacing & rwy occupancy time increases arrival capacity (I)	Runway occupancy time increase unless high-speed taxis available (H)
3-Precision Navigation/RNAV Routing	CNS equipment (I)	Reduced noise (I)	No benefits without advanced tools (I) Increase in capacity (I)	No direct Information
4--Two-segment Approach DC-8, B727, GSII, JS, HS125, SL-60, LJ24, BAC 1-11 (O) Large noise reduction dependent on aircraft Researched in 70s & 90s	Precision electronic vertical guidance, Autopilot (B)	50% NR (3-8.5dB) 60-65dBA CA=34% NR (O) 65-70dBA CA=52% NR 70-75 dBA CA=3% NR (O) EPNL NR betw 3-8.5 dBA due to increased altitude and decreased power (D) 2-6nm=10dB NR (O)	No direct information	No direct information

Table 3.2-2: Consolidation of Approach Procedures and Impact - Long-Term

(Letters in parentheses represent reference for information from Appendix B)

Procedure \ Impact	Safe for flight crew	Acceptable to flight crew & ATC?	Fuel Impact	Approach Time Impact
Long-term				
1--Advanced Continuous Descent Approach B747-400, Fokker 100 (G), B737-400 Researched in 90s	Safety aspects are not affected (I)	Reduction in controller workload (I)	Fuel conservation & low emissions due to idle thrust setting (G)	Reduced overall approach time to at least back to current (G)
2--Dual Threshold Trials performed at Frankfurt Researched in 90s	Concern with missed Approaches (H) Safety study is required (I) There are operational limitations (visibility, wind, turbulence) (I)	Work needed on procedures for missed approach (H)	No affect on fuel (H)	Faster due to 2 paths (H)
3-Precision Navigation/RNAV Routing	Safety is not affected (I)	Redistribution of workload between 2 Controller positions (tactical important) (I) Difficult on ATC--airspeeds are constantly changing, as are aircraft configurations (O) If implemented w/ adv. Tools & more accurate wind predictors, reduction of controller workload will reduce – no traffic guidance (I)	No direct information	No direct information
4--Two-segment Approach DC-8, B727, GSII, JS, HS125, SL-60, LJ24 (A) Large noise reduction dependent on aircraft Researched in 70s & 90s	Yes with conditions & good avionics (B) Yes (A)	Puts aircraft close to operating envelope (O) Increase in pilot workload (O) No additional workload for crew (E)	No direct information	No direct information

Table 3.2-2: Consolidation of Approach Procedures and Impact - Long-Term (Continued)

(Letters in parentheses represent reference for information from Appendix B)

Procedure \ Impact	Impact on Operator Economics	Constraints/Problems to be solved	Technology still needed
Long-term			
1--Advanced Continuous Descent Approach B747-400, Fokker 100, B737-400 Researched in 90s	No direct Information	Requires change in overall operational concept (I) On-board equipment & ATC system capabilities Required (M)	ATM/CNS equipment for both ground services and Aircraft (I)
2--Dual Threshold Trials performed at Frankfurt Researched in 90s	No direct Information	Wake turb., lim. rwy length, rwy occup. time, local rwy exits, MTDD, very dependent on arpt layout (needs long rwy to accommodate) (H, J) Airport dependent, missed approach procedures need to be developed (J)	Requires very accurate ILS (H)
3-Precision Navigation/RNAV Routing	No direct Information	Availability of new CNS equipment (I)	New arrival management tools and/or other aircraft sequencing aids needed (I)
4--Two-segment Approach DC-8, B727 (B), GSII, JS, HS125, SL-60, LJ24 (A) DC-8, B727 (O) Large noise reduction dependent on aircraft Researched in 70s & 90s	No direct Information	Restricted to certain weather conditions/tailwinds (K) DC-8-max 5.5deg, B727-max 5.2deg (a/c performance) (B) Few data available for bizjet class of aircraft (A)	DGPS & RNAV would help (O) Additional approach guidance for 1st segment (O) Autopilot or flight director coupling (O) Would need to use air-based instead of land-based navigation; not compatible w/ current ATC (O)

Table 3.2-2: Consolidation of Approach Procedures and Impact - Long-Term (Continued)
(Letters in parentheses represent reference for information from Appendix B)

3.2.1 Near-term Solutions

This discussion concerns the near-term *implementation* of each technique. Some solutions, quite obviously, will require either a longer research and development (R&D) time, or await developments that are known to be in the future, and so must be classified as intermediate or long term solutions.

3.2.1.1 CDA

This procedure has already been implemented at several airports (primarily in Europe), and could presumably be implemented anywhere. Due to the serious effect on arrival capacity, its usage has been limited to periods of lower demand (night). It is still useful, since evening and night operations are often a major subject of community noise concerns. Improvements to CDA can be achieved in the short term through development of aircraft performance databases, and ATC automation tools that can utilize those databases to achieve a diminished capacity impact.

3.2.1.2 Delayed/Reduced Flaps

These techniques have in many cases been implemented through careful modifications to airline policies and procedures. There is more room for improvement, but each step tends to reduce conventional operating safety margins (particularly regarding wind shear/downburst issues). These reductions must either be proven tolerable and safe through real-time simulation studies, or must be compensated for through other enhancements to air or ground capabilities.

3.2.1.3 Increased GS Intercept Altitude

This technique involves little other than intercepting the ILS GS signal at a higher altitude. The two current drawbacks are that terminal airspace routings may need to be modified, and the GS signal may not be reliable at the range involved. These are candidates to be to be near-term issues, since 1) the necessary TMA redesign can be done in the near term, and 2) there are near-term solutions to the intercept issue. These solutions are in the form of usage of GPS/FMS navigation to conduct the transition to intercept the glide path and/or GS siting or transmitter improvements. There are factors that may delay implementation, such as the potential need to conduct environmental impact studies regarding the revised arrival and departure routes.

3.2.1.4 Dual Threshold Approach

It is technically feasible to add an additional GS transmitter displaced down the runway from the threshold, but this is a very costly alternative. This can be implemented in the near term on a runway-by-runway basis (and has been done in Europe). However, for general application, this technique best awaits the availability of precision GPS/LAAS instrument approach capabilities. Independent sets of approach lighting systems would still be required. Note that LAAS implementation will most likely be achieved in the near term. The development and certification of the precision approach procedures based on GPS/LAAS themselves that may stretch out to the intermediate and even the long term.

3.2.1.5 Two-segment Approach

Researched since the early 1970s, implementation of this technique has awaited the type of precision navigation capability that is now available. It is arguable whether LAAS capability is needed for conducting the steep (intermediate) segment of a two-segment approach. However, it will still be necessary to develop these procedures through simulation studies, and demonstrate them to satisfy operators that they are practical. Once this is achieved, the operators will need to make equipment modifications, develop policies and procedures, and perform the required training. Given an accelerated, high-priority effort, this could be achieved in the near or intermediate term.

3.2.1.6 Precision Lateral Navigation

Precision navigation capability is not a prerequisite to the implementation of some of these procedures. However, the short final intercept procedure would require such a capability. Usage of GPS-based navigation via programmed FMS routes for noise-sensitive area avoidance and approach course intercept could be achieved in the very near term. Maintaining arrival capacity levels during peak hours may involve a form of speed control coupled with ATC automation enhancements (DST's and, possibly, data link). This would push at least part of this solution out into the intermediate-term category.

3.2.2 Intermediate-term Solutions

3.2.2.1 Advanced Continuous Descent Approach

This can be viewed as involving a short-term solution as well as one in the intermediate term. The short-term solution would be through development of ATC automation DSTs to aid the controller in predicting optimal descent initiation points and therefore, to control inter-arrival spacing. While not eliminating the capacity impacts of CDA, these impacts can be reduced considerably, allowing CDA to be extended to more traffic hours within the day. The intermediate-term solution is to develop a full ACDA capability (including real-time wind information, possibly provided by data link). Research, in the form of analytical studies and, possibly, real-time simulations will be needed to determine the extent to which capacity impacts can be eliminated.

3.2.2.2 *Delayed/Reduced Flaps; Delayed Landing Configuration*

Achievement of the most noise-optimum reduced flaps capabilities will be contingent upon deployment of advanced wind shear and downburst monitoring capabilities. These capabilities, based on Doppler radar and laser technologies, are either under development or have already been deployed at some locations. New (or enhanced) technologies (airborne and ground), that would perform similar air mass motion detection or prediction, may be required as well.

3.2.2.3 Two-segment Approach to Short Final

If conventional two-segment approach capabilities are not realized in the short term, they most certainly can be in the intermediate term. Full implementation of precision 3D navigation and advanced FMS capabilities may allow full implementation of the two-segment-to-short-final procedure (intercepting the GS path closer to one mile from touchdown), and possibly even more complex procedures.

3.2.2.4 Precision Lateral Navigation

The remaining capability that will require intermediate term development is the short final intercept procedure (analogous to the MLS curved approach procedure). This will allow noise-sensitive areas along the conventional approach course to be avoided. Several variables, such as the intercept angle, the intercept range (therefore, altitude) and arrival time control techniques, are all subjects requiring R&D. Ground-based technologies, such as precision monitoring equipment to detect overshoots and missed turns, may also require development.

3.2.3 Long-term Solutions

3.2.3.1 Increased GS Angle

While it is technically feasible in the short term to modify the descent gradient of a GS transmitting installation, it is very costly. Furthermore, there are aircraft types that may not be certifiable at a greater approach slope. Also, there are many operational issues that must be resolved prior to routine implementation of such procedures even given such certification. Solutions to these problems lie in the longer-term realm. A likely solution to the GS re-siting problem is the GPS/LAAS precision approach capability. Implementation of such a capability is probably inevitable, but will require extensive development, simulation and testing before being proven safe and acceptable.

3.2.3.2 Dual Threshold and Multi Threshold Approaches

The advent of the GPS/LAAS precision approach capability could enable dual or even multi threshold approach procedures to be implemented on a routine basis. Advanced technology could enable the specific touchdown point (and even descent gradient) to be changed to match the operational capabilities and/or noise characteristics of each arriving aircraft, considering current runway conditions. Avoidance of wake vortices can even be included in the implementation. The question of how approach lighting systems would need to be designed to support such a capability requires serious attention. Conventional lighting methods could not suffice, since they are designed to support touchdown at a specific, fixed point on the runway. An unconventional approach to lighting and visual guidance would be required. Also, considerable work may be necessary for development of safe and acceptable missed approach procedures.

3.2.3.3 Unified Approach Procedure

Full implementation of the unified approach concept is an objective whose development will be ongoing. Coupled with successful demonstration and implementation of the other intermediate and long-term procedures discussed here will be eventual integration of multiple such concepts into flight hardware and ATC automation capabilities.

4. Research Strategy for Procedural Noise Abatement Technologies

4.1 Research Areas

Successful implementation of noise abatement procedures will require R&D in three broad technical areas: Analysis and Design, Simulation and Refinement, and Technology Development. Analysis and Design relates to the analytical work, software development and fast-time simulation studies necessary to bring a concept to the point where cockpit simulation of the concept can be pursued. Simulation and Refinement relates to the detailed (in many cases high-fidelity) real-time simulation studies required to further develop, refine and prove out the concepts, with the next step being either flight test or operational demonstration. Technology Development relates to specific areas where enhancements to available technology are required.

The various types of research work suggested or hinted at in Section 3 are organized below within these three broad areas. This sets the stage for developing a strategy for achieving these objectives consistent with NASA's objectives and research orientation.

4.3.1 Analysis and Design

4.1.1.1 Aircraft Performance Modeling for Real-time ATC DST Applications

There is a need to develop tables of aircraft performance functional characteristics in the descent and low altitude regimes and for landing. These tables would contain the functional relationships of performance to specific aircraft type, weight, temperature, time of day, airline policies, and runway conditions. The tables of functions would be used for several purposes:

- For modeling anticipated descent performance (useful for improving CDA capacity performance, developing ACDA, and developing metering and sequencing DST technology). Descents constrained by constant Calibrated Air Speed (CAS), by constant gradient or by a more complex programmed trajectory could be included.
- For modeling low-altitude speed control tolerance (the ability to go faster or slower safely in current conditions). This will be primarily useful for noise reduction and for developing sequencing DSTs, including those supporting 4D (arrival time control) navigation.
- For modeling runway stopping distance requirements (for dual-threshold, or multiple-threshold applications; many other potential applications unrelated to the noise issue).

4.1.1.2 Remote Wind Sensing Requirements

It is important to determine the requirements of the sensed wind data. There are two primary applications for the data:

- Wind velocity in the along track direction on the final approach path. This data is needed in support of development of ACDA procedures and in support of 4D navigation. Requirements to be determined include the measurement accuracy, the specific measurement points of interest and the data timeliness requirement.
- 3D air mass motion (and prediction). This data is needed to provide reliable wind shear and downburst information in support of the reduced/delayed flap noise abatement technique. Requirements include measurement accuracy, reliability, timeliness and regions of coverage. Included with this requirement is a need to assess requirements of air mass motion modeling technologies intended for the prediction of impending air motion events.

There are several technologies that can be applied towards these objectives, which are in a reasonable high state of development, including Doppler radar and laser techniques and FMS sensing of current wind conditions.

4.1.1.3 GPS/LAAS/FMS Instrument Approach/ILS Transition Design

This is a broad area that encompasses the design of FMS functions such as the two-segment approach, the two-segment (or more complex) approach to short final, horizontal area coverage to short final, and GPS precision instrument approach (with ILS/GS crosscheck, or sole-means).

There are obviously a number of reasons to foster FMS development, including receiving the economic benefits of implementing precision approaches without incurring the costs of an ILS installation. The noise motivation is to keep aircraft higher over the approach path, or to 'bend' the approach path to provide a curved-path capability. The two-segment approach (the conventional technique, and two-segment to short final technique) and the area coverage to short final procedure are potential intermediate-term solutions, since the existing GS is utilized for the final segment.

An especially attractive capability is the two-segment to short final capability. This is true for several reasons. It can provide noise benefits of an even greater magnitude than the traditional two-segment approach, and it can provide benefits closer in to the runway. FCS technology has developed considerably in recent years. Combined with better aircraft performance modeling in the close-in transition-to-final regime, GPS/LAAS, and improved knowledge of tailwinds (capability '4.1.1.2' above), practical two-segment to short final approach capability could be implemented on a routine basis.

This research area should address the analysis and design issues, including software design, involved in creating further developments of FMS capabilities. This may involve interaction with manufacturers, airline operators and ATC personnel to ensure that concepts being implemented are done in a way that would be supported by the users. The objective is to develop FMS algorithms that are suitable subjects of real-time simulation studies for purposes of proving and refining the concepts.

Where appropriate, efforts in this research area should address the anticipated effects of these procedures and techniques on ATC procedures, data display requirements and controller workload issues.

4.1.1.4 Final Approach Path Monitoring Requirements

Monitoring of the final approach course with high resolution, accuracy and update rates may be needed to support certain noise reduction procedures. Two-segment approaches could be monitored to detect altitude deviations during the transition to a short final segment, or speed deviations during critical phases. Horizontal area coverage approaches to short final segments could be monitored to detect late turn-to-final events or turn overshoots. This is, of course, most important where parallel runways are used for simultaneous approaches. There is also a possible need for monitoring of CDA/ACDA and extended GS procedures to parallel runways where common intercept altitudes are used. The objective of this analysis and design task is to determine the monitoring requirements for implementing each of these noise-reduction procedural techniques. The required levels of measurement accuracy, reliability and update rate should be determined to meet the time-criticality requirements for recognizing deviations and executing correctional maneuvers.

4.1.1.5 Airspace Design and Benefit Prediction Tools

The need to improve terminal airspace design tools and, eventually, to develop a real-time capability to reconfigure the terminal area to accommodate local conditions leads to a need for developing a comprehensive set of automated airspace design tools. This analysis and design task will initially involve developing automated tools for evaluating the projected noise benefit impact that will result from implementing a specific procedure, or combination of procedures, at a real-world airport. A subsequent step will be to develop automated tools that can be utilized by airport management and ATC airspace personnel to interactively design modifications to airspace routes and procedures. These tools should not only provide verification of procedural conflict and terrain avoidance, and other route design services, but also provide an instant assessment of the projected noise impact consequences of a given change as it affects arrival, departure and over flight routings. Eventually, derivative tools could be used to optimize (on a noise basis) the choice of landing/takeoff configuration as influenced by current and runway wind conditions in real time.

4.1.1.6 Decision Support Tools/Automation Issues

Procedural noise reduction techniques will have several interactions with ATC automation developments, including decision support tools (DSTs). DST requirements include, in the short-term, the need for more advantageous usage of the CDA capability. Given better information and automated aids, controllers could obtain tighter in-trail control of aircraft utilizing the CDA procedure. The result will be to diminish the adverse capacity impact that currently exists. This will allow the CDA technique to be used over more hours of the day, while still avoiding those time periods when airport capacity is constrained. DSTs tailored to the ACDA task will be an integral part of that capability. The potential improvement to capacity that can result from implementation of ACDA should be evaluated through detailed real-time simulation studies (as outlined in 4.1.2.4) of ACDA including, if required, data-linked wind information. Objectives will also include determining ATC data display and controller procedure requirements.

4.1.2 Simulation and Refinement

4.1.2.1 GPS/LAAS/FMS Instrument Approach/ILS Transition Simulation

As the successor to the efforts described in 4.1.1.3, above, this research area will provide real-time simulation-based verification and refinement activities in support of development of FMS computational algorithms. The algorithms and piloting techniques being evaluated will eventually allow implementation of two-segment approaches, two-segment (or complex) approaches to a short final, horizontal area coverage to a short final (curved approaches), and GPS-based precision instrument approaches. Results of the simulations will be used to enhance the design of avionics algorithms, for pilot procedure development, ATC procedure development, training procedures development, and to demonstrate the benefits of the advanced cockpit automation capabilities.

4.1.2.2 Dual/Multiple Threshold Simulation

Based on GPS/LAAS instrument approach capability as the only viable intermediate-to-long term solution for implementing dual landing thresholds, the next challenge is to implement multiple landing thresholds. These could be tailored to the wake vortex sensitivities and stopping capabilities of the aircraft involved, therefore reducing noise on the approach to the maximum extent allowed by aircraft capabilities and runway conditions. Real-time simulation studies could be used to refine the DST algorithms involved in establishing the landing thresholds, for evaluating approach lighting concepts, and for demonstrating that vortex avoidance and stopping requirements are being met.

4.1.2.3 Final Approach Path Monitoring Simulation

In an effort to verify and refine the results derived analytically under 4.1.1.4, above, real-time simulation studies may be needed to address issues such as deviation detection times, warning response times, flight crew and aircraft dynamics correctional response times, etc. Particularly sensitive noise abatement procedures under examination include the two-segment (or complex path) approach to a short final segment, and the horizontal area coverage approach to a short final segment (involving parallel runways).

4.1.2.4 Decision Support Tools/Automation Issues Simulations

DSTs will need to be an integral part of the ACDA capability. The potential improvement to capacity that can result from implementation of ACDA will be evaluated through a detailed real-time simulation study of the ACDA function. This will be critical for refining the ACDA concept and proving that the capacity penalty is minimized, or eliminated. Real-time simulation will also be useful in refining and verifying other DST functions involved in implementing noise abatement procedures.

4.1.2.5 Wake Vortex Issues Simulations

In current operations, wake vortex effects are taken into account by categorizing aircraft according to weight and applying separation criteria according to these categories. Some of the noise abatement procedures (e.g., steep GS, two segment, and dual threshold approaches) may change the characteristics or location of the vortices as well as the flight regime of an aircraft when encountering vortices. Hence, wake vortex issues may affect the operational desirability of such procedures (positively or negatively). Given the complexities of vortex generation, vortex motion and settling, and the attitude and velocity of the encountering aircraft, fast-time and real-time simulation studies will be required for their evaluation and for procedure optimization.

4.1.3 Technology Development

4.1.3.1 Remote Wind Sensing Technology (Ground-based)

The specific requirements for wind sensing systems will have been defined as described in 4.1.1.2. This capability is needed at two levels, tailwind sensing and air mass motion sensing:

Tailwind sensing technology (e.g., using Doppler radar/lidar and/or data link of air-derived tailwind of preceding aircraft, or various sensors and atmospheric modeling)--This capability is needed to successfully implement ACDA with minimal capacity degradation. Combined with speed control tolerance modeling, it can be very useful in the functioning of sequencing DSTs.

Air mass sensing technology (very close ranges to the airport – less than two miles)--Rather than just tailwind measurement, 3D air movement (particularly vertical movement) data is needed. This information is critical to the implementation of delayed/reduced flap and delayed landing configuration noise reduction techniques where power and speed margins will be reduced. Accurate modeling of air mass movement is critical to maintaining safe operating margins during these procedures.

The objectives are to evaluate available technologies, perform trade-off analyses in areas where performance objectives cannot be met, and to plan development of advanced technologies where needed.

4.1.3.2 Remote Wind Sensing Technology (Airborne)

Utilizing forward-looking sensors of some form, air mass movement detection in the immediate path ahead would be very useful in providing the margin of safety needed for implementing the reduced/delayed flaps and landing configuration procedures. Based on the requirements as determined previously (4.1.1.2), available technologies will be evaluated, and plans for future technology developments will be developed.

4.1.3.3 Final Approach Path Monitoring Technology

The capability to independently monitor aircraft progress on final approach has been under development for a considerable time. Monitoring with high resolution, accuracy and update rates has been needed to support independent instrument approaches to closely spaced parallel runways. The primary purpose has been to detect lateral deviations from the approach path in time to provide evasive maneuver information to the other aircraft on the closely spaced approach. The purposes for noise reduction are somewhat different (although common technologies may apply). Two-segment approaches could be monitored to detect altitude deviations during the transition to the short final or speed deviations during critical phases. Horizontal area coverage approaches to short final segments could be monitored to detect late turn-to-final events or turn overshoots. This is, of course, most important where parallel runways are used for simultaneous approaches. Based on the requirements as determined under 4.1.1.4, current technologies will be evaluated and plans for new technology development will be made.

4.2 Plans of Other Agencies

Based on 1998 research, the NLR is now exploring additional benefits of ACDA, and evaluating its operational and economic feasibility. Within its Basic Research Programme, the NLR is carrying out research on “Medium term” noise abatement procedures, such as, advanced procedures for departures and arrivals. They are cooperating with the Russian Gromov Flight Research Institute in Zhukovsky Russia and the International Science and Technology Center (ISTC) in Brussels. They are planning to conduct flight trials with transport aircraft in some advanced approach procedures early in 2001.

NLR is also establishing a work group within the Group for Aeronautical Research and Technology in Europe (GARTEUR). This organization is formulating a plan for further noise research. The GARTEUR work group also has support of ADS Airbus Hamburg, European Aeronautic Defence and Space Company (EADS) Toulouse, and Dassault Aviation Merignac.

Mr. Louis J.J. Erkelens, Deputy Head Flight Mechanics Department, NLR in the Netherlands was contacted regarding future NLR research. In April 2000, the NLR carried out a series of 3 test flights with a Cessna Citation II research aircraft. During these trials they executed ACDA approaches at Groningen Airport (EHGG). This work was performed as a “piggy-back” project to another (Tunnel-in-the-Sky display) project. Three internal NLR memoranda related to this very limited effort were drafted concerning the flight test plan, description of the ACDA algorithm tests and a summary of the flight test results.

Another element of progress was a report on a study into the environmental and economic benefits (fuel savings) of CDA approaches. The results of this study are based on data collected from 10 actual KLM revenue flights with Boeing 747-400 and Boeing 737-300/400 aircraft. A paper on this study was presented on the Internoise Conference in Nice, France, 27-30 August 2000.

Currently, a new Consortium under the leadership of NLR submitted a project proposal to the European Commission for a follow-on project to SOURDINE called SOURDINE II. The decision is to be made in 2001. Total cost for this proposed project is estimated at 4.5 million Euros over three years. The project will focus on the development of enabling technology to achieve the successful introduction of the selected departure and approach procedures, such as ATC control tools, automated aircraft-ATC interaction tools and cockpit monitoring tools. SOURDINE II hopes to receive the assistance of Boeing and the FAA for the 5th Framework (the next stage).

Frankfort, Germany airport (FRA) is currently in the process of adding a new ILS system and a High Approach Landing System/Dual Threshold Operation to increase airport capacity. This enhancement is part of the "Stufenplan 2000" developed in cooperation with the German Air Navigation Services and Lufthansa. The findings in reference H by the Technische Universiteit Delft in the Netherlands regarding landing capacity of dual threshold runways will also be applied at FRA.

In the U.S., Chicago is undertaking a number of aviation technology integration initiatives. The city's administration made the decision in 1999 to take a proactive position in implementing technologies that would enhance safety, improve efficiency, track ground movement, improve asset management, and support environmental aims of the community. The enabling technologies of GPS and LAAS will be combined with Automatic Dependent Surveillance-Broadcast (ADS-B), and integrated via Geographic Information System (GIS). This effort is identified as the *Chicago Airport System Strategic Technology Initiative (CASSTI) (**http://www.ansp.com/CASSTI.htm**)* (reference R). This technology integration will provide next-generation (LAAS-based) precision approach capabilities enhancing access and efficiency, and improving delay at both O'Hare International Airport (ORD) and Midway Airport (MDW). It will provide airspace and ground movement management tools, establish advanced procedures taking advantage of airborne technologies, and introduce tools to automate airport mapping and enhance facilities management.

4.3 Strategic Research Plan

This plan is organized into four fundamental areas. The first three follow the organization of section 4.1. They are Analysis and Design, Simulation and Refinement, and Technology Development. A fourth area has been included here as it is a natural outgrowth of the other areas: Automation Technology Development.

These four areas are presented to form a logically cohesive plan. Only parts of this plan would be addressed and implemented by the NASA Langley Quiet Aircraft Technologies program. Their general areas of interest would include 4.3.1, Analysis and Design, and 4.3.2, Simulation and Refinement. A possible approach by that office to selecting priority tasks from those areas, and a potential schedule of such events, are presented in section 4.3.5. The remaining areas of this plan would more appropriately be subjects of other offices within NASA, and by the FAA, industry participants and international efforts.

In each paragraph below, mention is made of time period in which it would be appropriate to conduct the research. Near-term is nominally defined as through 2004, Intermediate-term through 2008, and Long-term as beyond 2008. These target *research* priorities should not be confused with the *implementation* terms mentioned in Section 3.2.

4.3.1 Analysis and Design

The first phase of the strategic plan for procedural noise abatement research is intended to address areas amenable to study through research, analysis, computer modeling and fast-time simulation.

4.3.1.1 Aircraft Performance Modeling for Real-time ATC DST Applications

4.3.1.1.1 Descent Performance Functions

Under this effort the aircraft types in use today at capacity-constrained airports will be identified (in detail to specific subtype). Detailed performance data will be obtained from manufacturers concerning the descent and low altitude cruise flight regimes. From this data the specific descent distances, fuel and time (from metering fix or holding pattern altitudes to GS intercept altitudes) will be derived for the CDA profile (idle thrust, constant airspeed). Also, descent fuel and time (over the range of altitude from the metering fix to the ground) will be derived for the constant gradient approach (at standard ILS descent gradient, and at higher gradients representative of two-segment procedures and the increased GS procedure). In both cases, the initial and final altitudes will be parameters, along with aircraft weight and air temperature. In the low altitude cruise regime, maximum and minimum cruise speeds, with aircraft weight and air temperature as parameters, will be modeled. Fuel consumption as a function of cruise speed will also be derived. This task, needed to introduce CDA procedures with a minimum of capacity impact, could be accomplished in 12 to 18 months. (Near-term effort)

4.3.1.1.2 Airline Policy Modeling

In order to further refine the models derived under 4.3.1.1.1, major airlines using these aircraft will be surveyed to collect information regarding their standard procedures and preferences as they apply to CDAs and low altitude maneuvering in general. In particular, company-specified procedures regarding flap extension, thrust management and preferred airspeeds will be obtained. This information will be combined with the appropriate modeling data from 4.3.3.1 to yield models where the specific airline is also a parameter. This effort will be conducted in parallel with the first effort. (Near-term effort)

4.3.1.1.3 Runway Stopping Distance Requirements

This task will begin with a search of runway characteristics and aircraft stopping distances available from the literature. Further testing, particularly at extremes of weather conditions and aircraft weight, will be specified to fill in any areas that are lacking in such data. The data so collected will be combined to create a model of stopping distance requirements versus aircraft type, touchdown speed, weather conditions and aircraft weight. This effort may commence roughly two to five years from the present since it is required in support of the dual threshold (and multiple threshold) approach procedures. (Near- and intermediate-term)

4.3.1.1.4 Runway Friction Monitoring Systems

These systems would be designed to monitor runway dampness, rate of water shedding during precipitation, and runway icing potential in order to characterize effects on braking distance. This is not anticipated to involve significant new technology, but perhaps rather a systems approach to the problem of characterizing stopping distance. Development schedule requirements are not critical since they will be paced by the need for such systems to support dual-threshold and multi-threshold approach procedures. (Intermediate-term effort)

4.3.1.1.5 (Fast-time) Simulation of Descent Procedures

In support of the conduct of research areas 4.3.1.1.1 through 4.3.1.1.4, fast-time simulation efforts involving detailed aerodynamic models may be necessary in some cases to effectively characterize certain noise abatement procedures and to develop data pertinent to their design and evaluation. (Near-term)

4.3.1.2 Remote Wind Sensing Requirements

Each of these areas involves the eventual development of operational systems to perform the indicated function, recognizing that currently available systems may be able to meet some or all of the requirements. These tasks relate to formulating the sensing and systems requirements of such systems. Later tasks will evaluate those requirements in the light of available technologies.

4.3.1.2.1 Air Mass Sensing (Ground-based)

Requirements for tailwind component sensing out to ranges of 15 nm, and three-dimensional wind detection out to a range of 2-3 nm are reasonable. Based on that background, the requirements of such sensors needed to support CDA, ACDA, and reduced/delayed flap and delayed landing configuration noise abatement techniques will be assessed. (Near-term)

4.3.1.2.2 Air Mass Sensing (Airborne)

Sensing requirements along the immediate forward path (1-2 nm), and at relative velocities of 120-200 kt., will be assessed. (Near-term)

4.3.1.3 GPS/LAAS/FMS Instrument Approach/ILS Transition Design

4.3.1.3.1 CDA Descent Procedures

Since no radically new procedures or technology are required in order to develop the CDA procedure, procedure development is a relatively minor exercise. It could be begun immediately. (Near-term)

4.3.1.3.2 Two-segment Approach Procedures

Standard two-segment approach procedures are designed with the intercept of the ILS GS from three to seven miles out. Procedures need to be developed applying the two-segment procedure to modern airline aircraft. The 'cleaner' nature of today's aircraft may, however, raise questions regarding the transition from the higher gradient to the GS gradient. Analysis and (possibly) fast-time simulation will be required to resolve that issue, and to collect data in preparation for simulator studies. Efforts could be initiated immediately. (Near-term)

4.3.1.3.3 Two-segment to Short-Final Procedures

This effort will involve exploring new territory: the safe transition from a high-gradient descent to the GS gradient only a short distance before the decision height is reached. The first step will be to explore and characterize safe methods for accomplish this using analytical tools and fast-time simulation. The simulation software must be of considerable fidelity in modeling low-speed aircraft dynamics, the functioning of the flight control system, the functioning of the GPS/LAAS navigation sensor, and the atmosphere. The simulation will also be used to evaluate FMS algorithms developed for this specific purpose. Given that these studies result in the conclusion that such procedures are safe and feasible, plans for real-time simulation studies of the concepts developed will be formulated. Such plans would include assessing the effects not only on pilot procedures, but also on controller procedures and other ATC issues. These initial efforts could be begun within two to five years, and will probably require two or more years to complete. (Near- and intermediate-term)

4.3.1.3.4 Lateral Navigation to Short-final Procedures

As in the two-segment-to-short-final case, the lateral navigation to short-final procedure is a new type of procedure. However, there was a considerable amount of analysis, simulation and testing conducted during the 1980s under the MLS program. The so-called 'curved approach' capability of MLS is directly analogous to the current case. The difference being that the area coverage navigation system is not MLS but GPS/LAAS. In both cases, a transition to a standard (but short) final approach segment is to be conducted. The work required here is somewhat analogous to the 4.3.1.3.3 research area, with considerable differences in scope and emphasis. Fast-time simulation is required only to identify the flight control system design problems that must be addressed. Work on FCS algorithm development could be begun almost immediately. Efforts to identify and define changes to controller procedures and ATC data display requirements should be begun concurrently. Planning for real-time simulator testing could begin after one to two years. (Near-term)

4.3.1.3.5 Increased GS Angle Approach Procedures

These procedures would involve a steeper descent gradient down to flare. It can only be accomplished by re-siting a GS installation, or after approval of GPS/LAAS as a sole-means precision approach system. Most transport aircraft are certified at present-day standard approach gradients for the transition to flare and landing. It is therefore unlikely that this procedure would gain acceptance in the near future. If explored, it will probably be done as a part of the process of certifying GPS/LAAS for precision instrument approach. Due to certification limits of current aircraft, the range of increased gradients available will be rather limited. Analytical and procedural development efforts could be begun as GPS/LAAS instrument approach techniques mature. Initial analytical efforts would be aimed at evaluating the potential limiting gradients associated with each aircraft type in the current airline fleet. (Intermediate-term)

4.3.1.3.6 FMS Developments for CDA, ACDA

Some FMS development work will be required to accommodate these procedures, particularly in the ACDA case where data-linked or airborne tailwind profile data and high-fidelity aircraft descent performance models would be available as a part of the ACDA equation. Choosing the optimum descent initiation point based on accurate navigation and wind information is important to obtaining the greatest runway capacity from the concept. Detailed development of such algorithms will set the stage for later real-time simulation studies. In parallel with 4.3.1.6, analyses of necessary changes to ATC automation, data display requirements and controller procedures should be conducted. This effort could be initiated within one to two years, and then continue on as ACDA refinements are developed. (Near- to intermediate-term)

4.3.1.4 Final Approach Path Monitoring Requirements

Independent flight progress monitoring systems may be required for two specific situations: the two-segment to short-final procedure and the lateral navigation to short-final procedure. In the first case, requirements for sensing vertical deviations and airspeed deviations from the intended profile must be determined. In the second case, lateral excursions, particularly during intercept of the final approach course are to be sensed. Work need not be initiated immediately since demonstration and operator acceptance of these procedures is still some time off into the future. (Intermediate-term)

4.3.1.5 Airspace Design and Benefit Prediction Tools

4.3.1.5.1 Noise Benefit Impact Model

This effort involves development of a model designed to assess the noise benefit to be expected upon implementing a specific noise abatement procedure, or combination of such procedures. Development of this model will allow analysis of alternative procedures in actual real-world terminal areas, and verification of the level of benefits to be realized overall. This effort can be begun immediately. (Near-term)

4.3.1.5.2 Airspace Route Modification Tool

Under this effort a tool will be developed which allows airport operators and airspace planners to interactively plan modifications to terminal route structures. The tool, in addition to performing airspace design functions, such as development of conflict-free paths and avoiding restricted areas and terrain, would also generate assessments of the total impact of any change on noise, considering arrivals, departures and over flights. It would model the effects of changes such as increased GS intercept altitude (extended GS) on current airspace routings. The models would suggest changes to routings, and allow interactive design of altered routes. Initiation of this effort could probably begin within two to five years. (Near- to intermediate-term)

4.3.1.5.3 Real-time Airspace Configuration Tool

A logical derivative of the aforementioned tools would be eventual development of a real-time terminal configuration tool. It would be used to specify the noise-optimal terminal route configuration as a function of prevailing wind, traffic demand level, time of day, closed runways, inoperative landing systems or communications equipment, etc. Development of this tool is probably a long way off. (Long-term)

4.3.1.6 Decision Support Tools/Automation Issues Characterization

This effort would develop the requirements for ATC automation enhancements (such as DSTs) that will be needed to support CDA and ACDA procedures. The intent is to characterize the automation capabilities so that they can be factored into the design of avionics algorithms and, eventually, into the models supporting the real-time simulation studies. Determination of probable impacts on ATC display requirements and controller procedures is also an objective. Efforts in this area should be initiated within the first year, so that the other modeling efforts are not impeded. (Near-term)

4.3.2 Simulation and Refinement

This phase of the strategic plan for procedural noise abatement research groups together the research activities centering around real-time simulation. Activities included here are simulation study planning, real-time simulation studies, reevaluation of underlying procedures, technologies, algorithms and design (i.e, refinement), and generation of outputs. These outputs include piloting procedures and training recommendations, ATC data requirements and controller procedures, avionics algorithm definitions, and recommendations for avionics standards development.

4.3.2.1 GPS/LAAS/FMS Instrument Approach/ILS Transition Simulations

This is a very large category of simulation research efforts because it includes, in addition to the basic problem of GPS/LAAS-based instrument approaches, many of the issues discussed under 4.3.1.3. This category includes the following specific areas of research:

4.3.2.1.1 GPS/LAAS-based Precision Approach Development (Cat I and beyond)

Subjects include piloting issues, FMS/FCS issues, assurance and redundancy issues as they apply to GPS-based Cat I approaches with and without underlying ILS (sole means), and to higher category approaches. (Near- to intermediate-term)

4.3.2.1.2 Two-segment Approach Procedures

Piloting and FMS/FCS issues during standard two-segment approach procedures are subjects in this area. (Near-term)

4.3.2.1.3 Two-segment to Short-final Procedures

The concept of conducting vertical profiles to a short (roughly one mile) stabilized segment along the standard GS brings up new issues regarding design of the FMS and FCS systems, piloting procedures, controller procedures, redundancy and cross-check requirements, flap and drag device scheduling, and wake vortex issues. (Intermediate-term)

4.3.2.1.4 Lateral Navigation to Short-final Procedures

The concept of conducting lateral navigation noise-abatement and time-control profiles to intercept a short final segment (three miles or less) brings up issues regarding FMS design, piloting procedures, controller procedures, redundancy and cross-check requirements. (Near-term)

4.3.2.1.5 Increased GS Angle Procedures

Successfully implementing increased GS angle procedures brings up simulation study issues that would probably be addressed on many fronts due to the aircraft certification issues that are raised. Manufacturers and airline operators would probably be primarily involved in conducting such studies. (Intermediate-term)

4.3.2.1.6 ACDA FMS Issues

While the CDA approach procedure brings up few issues requiring simulator evaluation, the ACDA procedure, in attempting to precisely control descent in a very predictable way, brings up issues in aircraft performance modeling, FMS design, piloting procedures, controller procedures, and contingency procedures. (Near- to intermediate-term)

4.3.2.2 Dual/Multiple Threshold Simulation

There are few procedural or control issues associated with the availability of dual, fixed GS paths other than frequency selection and available runway length confusion issues. Where the descent point can be varied (given GPS/LAAS-based approaches), either from day-to-day, or in real time as a function of an aircraft's capabilities, weather conditions, wake vortex sensitivity, etc., new issues arise. Independent verification of a safe approach and landing, by ATC and by the flight crew, is paramount before such procedures can be implemented. Threshold designation, approach lighting identification and communications issues are also important. (Intermediate-term)

4.3.2.3 Final Approach Path Monitoring Simulation

Under section 4.3.1.4 the requirements of approach path monitoring systems which may be needed to support short-final intercept procedures (both in the vertical and lateral planes) are discussed. The process of developing such requirements may result in the need to utilize real-time simulation to address issues such as warning time requirements, controller awareness requirements, pilot response times, additive effects of late maneuvers with changing wind conditions, etc. (Intermediate-term)

4.3.2.4 Decision Support Tools/Automation Issues Simulations

In the normal process of DST development, many alternatives regarding algorithm design will arise. These may not all be resolvable through analysis, therefore involving real-time simulation studies with the pilot and controller in the loop. Such techniques can also be applied before initial deployment of a new DST package, for verification and refinement purposes. (Intermediate- to long-term)

4.3.2.5 Wake Vortex Issues Simulations

As new flight regimes are introduced, such as short-final intercepts, curved approaches, two-segment (or more complex) approaches and dual/multiple thresholds, new wake vortex generation and encounter issues are introduced. While the generation of vortices is best addressed with aerodynamic models and, possibly, flight test, the encounter issue is directly addressable with real-time simulation. The particular route geometry, leading aircraft vortex characteristics, vortex motion and settling conditions, and trailing aircraft control authority can be modeled in order to develop practical vortex avoidance procedures and standards. (Intermediate-term)

4.3.2.6 Reduced/Delayed Flap Issues Simulations

The further implementation of reduced/delayed flap techniques will certainly involve real-time simulation studies. Particularly from the viewpoint of developing pilot procedures and training requirements, and verifying pilot comfort with remaining control margins, simulation studies will be a very useful tool. (Near-term)

4.3.3 Technology Development

This phase of the strategic plan for procedural noise abatement research examines issues of more fundamental technology development that may arise as the requirements of the various subsystems become more clearly defined. These research areas encompass fundamental technology development areas, where a functioning system is not the immediately intended result. Note that each of these areas involves continuation of current work. Therefore, efforts would commence once the requirements have been defined.

4.3.3.1 Remote wind sensing technology (ground-based)

Each of these areas involves the eventual development of operational systems to perform the indicated function. Since some of these areas may require technology development (and possibly some breakthroughs) it may be premature to estimate a schedule for development at this time.

4.3.3.1.1 Air Mass Sensing (Ground-based)

Based on the present status of air mass movement remote detection technologies (Doppler radar, laser techniques, and acoustic techniques), further research in remote air mass sensing would be accomplished. Tailwind component sensing out to ranges of 15 nm, and three dimensional (in particular, tailwind and vertical wind) detection out to a range of 2-3 nm are needed to support CDA, ACDA, and reduced/delayed flap and delayed landing configuration noise abatement techniques. Quite obviously, there are interactions with current efforts at detecting wind shear and downburst components (during final approach) that are presently in development or under deployment. (Near-term)

4.3.3.1.2 Atmospheric Modeling

In lieu of direct sensing of tailwind and vertical wind components along the approach path, the usage of other sensors (anemometer arrays, remotely-located radar/laser devices, NWS data, etc.) with atmospheric modeling algorithms could possibly result in the derivation or prediction of the desired information. (Near-term)

4.3.3.2 Remote Wind Sensing Technology (Airborne)

Application of remote air mass movement sensing technologies to the airborne environment would enable advanced application of reduced/delayed flap and delayed landing configuration regardless of the existence of ground-based capability or data link. The operating environment and sensor requirements are different, given installation on a moving aircraft. Sensing is only needed along the immediate forward path (1-2 nm), but at relative velocities of 120-200 kt. R&D of feasible means of providing this capability could be initiated immediately. Successful results could also be helpful in support of the two-segment-to-short-final procedure. (Near-term)

4.3.3.3 Final Approach Path Monitoring Technology

Precision approach monitoring using the Mode S transponder and specially-designed ground antenna arrays has been under development, test and demonstration for ten years or more, with the objective of monitoring closely-spaced parallel approaches. This technique, and any other promising approaches, may be developed further for the purpose of monitoring the two-segment to short-final procedures and lateral navigation to short-final procedures. Work could be initiated in the near future, with development schedules set to meld with the demonstration programs for those two procedures. (Intermediate-term)

4.3.4 Automation Technology Development

Interactions with the CTAS program are needed in specific areas to support the implementation of noise abatement procedures. Also, some of the technologies needed for noise abatement will have beneficial interactions with CTAS capabilities, which may impact CTAS development.

4.3.4.1 Enhancement to Final Approach Sequencing (Wind sensor data)

This research area addresses the eventual ability to use enhanced tailwind sensing capabilities, if further development of these capabilities occurs as stated in research area 4.3.3.1, for enhancing the performance of approach sequencing automation tools. Efforts would begin after successful system development. (Intermediate-term)

4.3.4.2 ***Integration*** of Final Approach Monitoring

Given the successful development of precision approach monitoring systems (for use in monitoring short-final approach noise abatement techniques) in research area 4.3.3.3, interactions would be necessary with CTAS automation. These would involve time-critical handling of the monitor data, and uplink of emergency clearances to aircraft on final approach. (Intermediate-term)

4.3.4.3 DSTs to Implement CDA Procedures & ACDA Procedures

It will be necessary to develop Decision Support Tools that will aid the controller in utilizing CDA and ACDA noise abatement techniques in a manner, which will result in minimized capacity impacts. DSTs for CDA would utilize the aircraft modeling information (to be developed under research area 4.3.1.1) and, eventually, sensed tailwind information (4.3.1.2) to optimize the choice of descent-initiation point for a CDA descent from a capacity viewpoint. The further usage of this information, including data link of tailwind information to the aircraft (supporting ACDA implementation) would be required. The CDA DST development effort could begin immediately after modeling results are available. The ACDA DST effort could begin as tailwind-sensing requirements become defined. (Near-term)

4.3.5 Candidate Schedule of Events

In Table 4.3-1 a summary of the above research topics is presented with annotation of the recommended research time period for each. A column is also shown that indicates whether each topic could be considered to be among the research priorities and orientation of the NASA Langley QAT program. The items of potential QAT interest are presented again in Table 4.3-2 along with an indication of recommended research priority level. Limitations of budget and personnel, and considerations of payoff versus cost, obviously reduce the list of items in which NASA involvement will eventuate. The priorities shown are based on the engineering judgment of the authors.

In order to arrive at priorities, and a candidate schedule of research tasks, it is first necessary to identify the most appropriate noise abatement procedure objectives to pursue. Considerations of expediency and immediacy of application, as well as potential noise payoff with minimal disadvantages, go into such an assessment. Five areas have been identified, and are listed below in rough sequence by implementation date:

- CDA (immediate, in certain applications)
- Extended GS (immediate, in certain applications)
- Precision Lateral Navigation (immediate, in certain applications)
- Extensions to CDA, culminating in ACDA (starting in 2-3 years)
- Two Segment (starting in 2-3 years)

The near-term research areas proposed here are oriented towards maximizing benefit, minimizing disadvantages and broadening the areas of application of each of these procedures. Thus, it is appropriate to examine the 'thread' of research activities necessary to realize the full potential of each type of procedure, and then concentrate emphasis on those research areas yielding the greatest overall benefit.

Development of enhancements to the CDA procedure (including development of ACDA) involves a) Aircraft Performance Modeling (4.3.1.1.1, 4.3.1.1.2, 4.3.1.1.5), Air Mass Sensing Requirements (4.3.1.2.1), CDA Descent Procedures (4.3.1.3.1), FMS Developments for CDA/ACDA (4.3.1.3.6), Noise Benefit Impact Model (4.3.1.5.1), Decision Support Tools Characterization (4.3.1.6) and ACDA FMS Issues Simulations (4.3.2.1.6).

Application of the Extended GS procedure involves the Noise Benefit Impact Model (4.3.1.5.1) and Airspace Route Modification Tool (4.3.1.5.2).

Implementation of the Precision Lateral Navigation procedure involves Lateral Navigation to Short Final Procedures (4.3.1.3.4), Final Approach Path Monitoring Requirements (4.3.1.4), Noise Benefit Impact Model (4.3.1.5.1), Airspace Route Modification Tool (4.3.1.5.2), Decision Support Tools Characterization (4.3.1.6), and Lateral Navigation to Short Final Simulations (4.3.2.1.4).

Table 4.3-1 Implementation Time period of Suggested Research Areas
N= near-term (to 2004), I= intermediate (2005-2008), L= long-term (beyond 2008)

N	I	L	QAT	Research Area
				4.3.1 Analysis and Design
				4.3.1.1 Aircraft Performance Modeling for Real-time ATC DST Applications
N			Y	4.3.1.1.1 Descent Performance Functions
N			Y	4.3.1.1.2 Airline Policy Modeling
	I		Y	4.3.1.1.3 Runway Stopping Distance Requirements
	I			4.3.1.1.4 Runway Friction Monitoring Systems Requirements
N			Y	4.3.1.1.5 (Fast-time) Simulation of Descent Procedures
				4.3.1.2 Remote Wind Sensing Requirements
N			Y	4.3.1.2.1 Air Mass Sensing Requirements (Ground-based)
N			Y	4.3.1.2.2 Air Mass Sensing Requirements (Airborne)
				4.3.1.3 GPS/LAAS/FMS Instrument Approach/ILS Transition Design
				4.3.1.3.1 CDA Descent Procedures
N			Y	4.3.1.3.2 Two-segment Approach Procedures
N			Y	4.3.1.3.3 Two-segment to Short-Final Procedures
	I		Y	4.3.1.3.4 Lateral Navigation to Short-final Procedures
N			Y	4.3.1.3.5 Increased GS Angle Approach Procedures
	I		Y	4.3.1.3.6 FMS Developments for CDA, ACDA
N			Y	4.3.1.4 Final Approach Path Monitoring Requirements
	I		Y	4.3.1.5 Airspace Design and Benefit Prediction Tools
				4.3.1.5.1 Noise Benefit Impact Model
N			Y	4.3.1.5.2 Airspace Route Modification Tool
	I		Y	4.3.1.5.3 Real-time Airspace Configuration Tool
		L		4.3.1.6 Decision Support Tools/Automation Issues Characterization
N			Y	
				4.3.2 Simulation and Refinement
				4.3.2.1 GPS/LAAS/FMS Instrument Approach/ILS Transition Simulation
	I		Y	4.3.2.1.1 GPS/LAAS-based Precision Approach Development (Cat I and beyond)
N			Y	4.3.2.1.2 Two-segment Approach Procedures
	I		Y	4.3.2.1.3 Two-segment to Short-final Procedures
	I		Y	4.3.2.1.4 Lateral Navigation to Short-final Procedures
	I		Y	4.3.2.1.5 Increased GS Angle Procedures
N			Y	4.3.2.1.6 ACDA FMS Issues
	I			4.3.2.2 Dual/Multiple Threshold Simulation
	I		Y	4.3.2.3 Final Approach Path Monitoring Simulation
	I	L		4.3.2.4 Decision Support Tools/Automation Issues Simulations
	I			4.3.2.5 Wake Vortex Issues Simulations
N				4.3.2.6 Reduced/Delayed Flaps Issues Simulations

Table 4.3-1 (Continued)

N	I	L	QAT	Research Area
				4.3.3 Technology Development
				4.3.3.1 Remote Wind Sensing Technology (Ground-based)
N				4.3.3.1.1 Air Mass Sensing (Ground-based)
N				4.3.3.1.2 Atmospheric Modeling
N				4.3.3.2 Remote Wind Sensing Technology (Airborne)
N				4.3.3.3 Final Approach Path Monitoring Technology
				4.3.4 Automation Technology Development
	I			4.3.4.1 Enhancements to Final Approach Sequencing (Wind Data)
	I			4.3.4.2 Integration of Final Approach Monitoring
N				4.3.4.3 DSTs to Implement CDA Procedures & ACDA Procedures

Implementing Two-segment procedures involves the Aircraft Performance Modeling group (4.3.1.1.1, 4.3.1.1.2, 4.3.1.1.5), Two-segment Approach Procedures Design (4.3.1.3.2), Noise Benefit Impact Model (4.3.1.5.1), Airspace Route Modification Tool (4.3.1.5.2) and Two-segment Approach Procedures Simulations (4.3.2.1.2).

Based on commonality of requirements, several efforts stand out. All the procedures require the Noise Benefit Impact Model (4.3.1.5.1), followed by its extension, the Airspace Route Modification Tool (4.3.1.5.2). Since development of an airspace design tool (4.3.1.5.2) is not within the normal QAT Office purview, their function would be promoting and coordinating its development by other areas of NASA and the FAA.

Two of the four threads of development involve the Aircraft Performance Modeling group (4.3.1.1.1, 4.3.1.1.2, 4.3.1.1.5). Two of the four also involve Decision Support Tools Characterization (4.3.1.6). One involves Air Mass Sensing Requirements (4.3.1.2.1), but other procedures to be implemented in the intermediate term (such as Reduced/delayed Flaps) would also require this step. One involves Final Approach Path Monitoring Requirements (4.3.1.4), but other future procedures, such as Two-segment to Short Final, also have this requirement.

Requirements specific to the individual procedures are as follows:

CDA/ACDA: CDA Descent Procedures (4.3.1.3.1), FMS Developments for CDA/ACDA (4.3.1.3.6), and ACDA FMS Issues Simulations (4.3.2.1.6)

Extended GS: None

Precision Lateral Navigation: Lateral Navigation to Short Final Procedures (4.3.1.3.4) and Lateral Navigation to Short Final Simulations (4.3.2.1.4)

Two-segment: Two-segment Approach Procedure Design (4.3.1.3.2) and Two-segment Approach Procedures Simulations (4.3.2.1.2)

Due to the pre-eminent importance of the CDA/ACDA concept, its research requirements would have highest priority, followed by Extended GS (which has no specific research requirements). Due to the imminent availability of Precision Lateral Navigation capability, it takes third priority. The Two-segment procedures, while of great importance, require more development work, putting them fourth on the list.

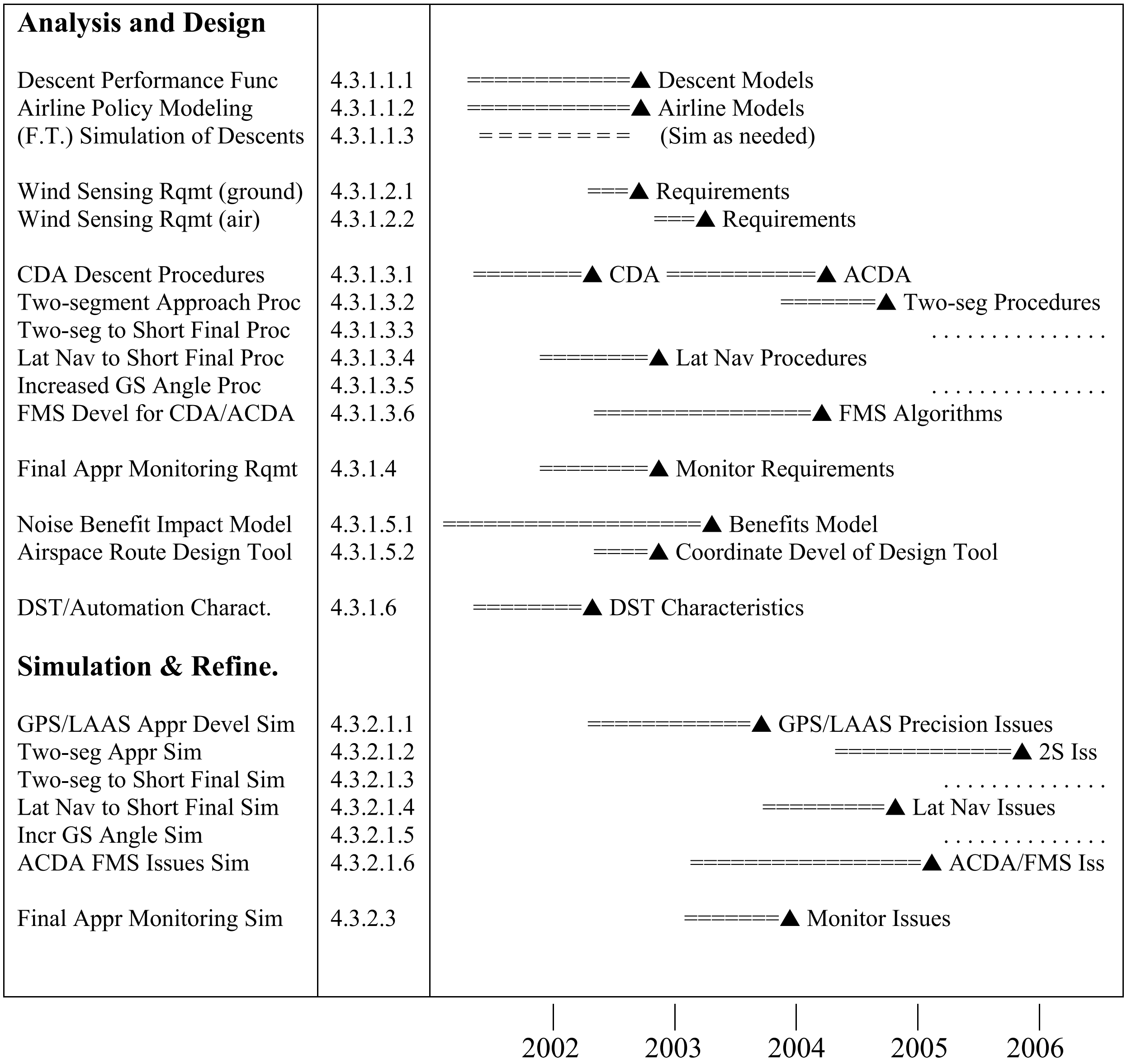
These priorities so developed are reflected in Table 4.2. To arrive at priorities for the remaining research areas, the time phasing of the eventual procedure implementation as well as benefit/cost probabilities have been factored in, realizing that they all must have priorities equal to or lower than those mentioned to this point.

Based on priorities and time-phasing requirements, a candidate development schedule for QAT Office sponsored research efforts is presented in Figure 4.1. It is recognized that the list and schedule presented probably exceed the resources of that office. However, this is a starting point from which a realistic effort may be planned, assuming that some of these efforts would have to be conducted by others in NASA, the FAA, industry, and internationally.

Table 4.3-2 Relative Priorities of Potential QAT Research Tasks
N=near term (to 2004), I=intermediate (2005-2008), L=long term (beyond 2008)
Priorities: L-low, M=medium, H=high

N	I	L	Priority	Research Area
				4.3.1 Analysis and Design
				4.3.1.1 Aircraft Performance Modeling for Real-time ATC DST Applications
N			H	4.3.1.1.1 Descent Performance Functions
N			H	4.3.1.1.2 Airline Policy Modeling
	I		L	4.3.1.1.3 Runway Stopping Distance Requirements
N			H	4.3.1.1.5 (Fast-time) Simulation of Descent Procedures
				4.3.1.2 Remote Wind Sensing Requirements
N			H	4.3.1.2.1 Air Mass Sensing Requirements (Ground-based)
N			M	4.3.1.2.2 Air Mass Sensing Requirements (Airborne)
				4.3.1.3 GPS/LAAS/FMS Instrument Approach/ILS Transition Design
				4.3.1.3.1 CDA Descent Procedures
N			H	4.3.1.3.2 Two-segment Approach Procedures
N			M	4.3.1.3.3 Two-segment to Short-Final Procedures
	I		L	4.3.1.3.4 Lateral Navigation to Short-final Procedures
N			M	4.3.1.3.5 Increased GS Angle Approach Procedures
	I		L	4.3.1.3.6 FMS Developments for CDA, ACDA
				4.3.1.4 Final Approach Path Monitoring Requirements
N			H	4.3.1.5 Airspace Design and Benefit Prediction Tools
	I		H	4.3.1.5.1 Noise Benefit Impact Model
				4.3.1.5.2 Airspace Route Modification Tool
N			H	4.3.1.6 Decision Support Tools/Automation Issues Characterization
	I		H	
N			H	**4.3.2 Simulation and Refinement**
				4.3.2.1 GPS/LAAS/FMS Instrument Approach/ILS Transition Simulation
	I		M	4.3.2.1.1 GPS/LAAS-based Precision Approach Development (Cat I and beyond)
N			M	4.3.2.1.2 Two-segment Approach Procedures
	I		L	4.3.2.1.3 Two-segment to Short-final Procedures
	I		M	4.3.2.1.4 Lateral Navigation to Short-final Procedures
	I		L	4.3.2.1.5 Increased GS Angle Procedures
N			H	4.3.2.1.6 ACDA FMS Issues
	I		L	4.3.2.3 Final Approach Path Monitoring Simulation

Figure 4.1 QAT Office Program Candidate Task Implementation Schedule



Analysis and Design		
Descent Performance Func	4.3.1.1.1	============▲ Descent Models
Airline Policy Modeling	4.3.1.1.2	============▲ Airline Models
(F.T.) Simulation of Descents	4.3.1.1.3	= = = = = = = = (Sim as needed)
Wind Sensing Rqmt (ground)	4.3.1.2.1	===▲ Requirements
Wind Sensing Rqmt (air)	4.3.1.2.2	===▲ Requirements
CDA Descent Procedures	4.3.1.3.1	========▲ CDA ===========▲ ACDA
Two-segment Approach Proc	4.3.1.3.2	=======▲ Two-seg Procedures
Two-seg to Short Final Proc	4.3.1.3.3	. . . .
Lat Nav to Short Final Proc	4.3.1.3.4	========▲ Lat Nav Procedures
Increased GS Angle Proc	4.3.1.3.5	. . . .
FMS Devel for CDA/ACDA	4.3.1.3.6	================▲ FMS Algorithms
Final Appr Monitoring Rqmt	4.3.1.4	========▲ Monitor Requirements
Noise Benefit Impact Model	4.3.1.5.1	===================▲ Benefits Model
Airspace Route Design Tool	4.3.1.5.2	====▲ Coordinate Devel of Design Tool
DST/Automation Charact.	4.3.1.6	========▲ DST Characteristics
Simulation & Refine.		
GPS/LAAS Appr Devel Sim	4.3.2.1.1	============▲ GPS/LAAS Precision Issues
Two-seg Appr Sim	4.3.2.1.2	=============▲ 2S Iss
Two-seg to Short Final Sim	4.3.2.1.3	. . . .
Lat Nav to Short Final Sim	4.3.2.1.4	=========▲ Lat Nav Issues
Incr GS Angle Sim	4.3.2.1.5	. . . .
ACDA FMS Issues Sim	4.3.2.1.6	=================▲ ACDA/FMS Iss
Final Appr Monitoring Sim	4.3.2.3	=======▲ Monitor Issues

4.4 Research Product Transfer to National Airspace System (NAS) Operations

The opportunities for implementing, in NAS operations, the research findings that will result from executing this strategic plan are numerous. The plan presented has included those steps required, over and above basic technology development, which are needed to bring the research to implementation. For example, research area 1.1 ‘Air mass sensing (ground based)’ explores developments in technology that will result in a tool to accurately measure tailwind component along the approach path. Research area 5.1 develops that concept into a workable system. Areas 2.1 and 2.3 are designed to integrate this data into CTAS automation for implementation of CDA and ACDA procedures. Area 3.1, aided by the simulation work of area 7.1, in conjunction with areas 3.2 and 4.1, provides the operational data and airline constraints to result in a workable system acceptable to the operators. Area 6.2 fosters development of FMS technology as needed to implement CDA and ACDA as airborne procedures. CDA approaches, to be followed by ACDA approaches, can be implemented without delay.

- The strategy of the sponsor to not only conduct research, but also implement the results in the NAS can involve three activities, each of which takes advantage of their unique involvement in current NAS development:

- The role of NASA in the design and development of new CTAS automation concepts and tools allows them to forge ahead with development of tools that are needed to implement procedural noise abatement solutions. This particularly involves the CDA and ACDA concepts, and integration of two-segment-to-short-final and lateral navigation to short-final procedures, where new functionality in ATC automation and systems is needed. It should be noted that airborne procedures and new controller DSTs should be developed in parallel as the effectiveness of one may be strongly dependent on the effectiveness of the other.

- The role of NASA as a partner to the FAA in implementing new ATC systems and technologies allows them to work with FAA standards development offices and the RTCA by providing simulation and flight test data and systems analysis results. This has particular implications in any areas where airspace usage is an issue, such as two-segment approaches, two-segment-to-short-final approaches, lateral navigation to short-final approaches, and GPS/LAAS as sole means approaches.

- The role of NASA in fostering technology transfer allows them to become leaders in sponsoring joint government/industry/airport operator working groups aimed at implementing noise abatement procedures. These efforts not only help secure needed operational and flight test data, but also aid in promoting acceptance of the resulting procedures. Involving both the airline operator and avionics manufacturing segments of industry, these working groups can be utilized in implementing all of the noise abatement procedures.

Successful implementation within the NAS will, of course, receive the further impetus from airport operators and airlines as airport capacity tends to become constrained due to noise issues. This will help ensure cooperation among all parties in completing these efforts.

5. Conclusions and Recommendations

Engine, airframe and nacelle design improvements over the past twenty years have resulted in sharp reductions to engine noise in the approach and departure phases of flight. However, the amount of noise reduction that can be realized from further aircraft improvements is becoming limited. Noise continues to be a premier issue that threatens to limit the capacity at the nation's airports. Procedural improvements, studied at length in the 1970s but mostly placed on hold due to technology limitations of the time, have now become of great importance.

It is quite apparent that procedural improvements can yield significant benefits in terms of noise mitigation. However, the several candidate procedures will require varying levels of technology development and other investment commitments. In some cases, benefits can be obtained in the relatively near future. Decisions must be made regarding the sequence in which limited available capital is committed in fostering the development of these objectives.

It is recognized that the actual process of developing these procedures can be focused towards developing a unified procedure, as introduced in section 3.1.1. If the multiple procedures options available are considered together during the development of the techniques and the FMS system improvements required for their execution, several benefits can result: optimal use of available data, airspace and resources, and optimal noise reductions. This development process can proceed in such a way as to yield (as byproducts along the way) interim improvements (such as improved CDA procedures), which can be conducted using conventional aircraft systems.

It is recommended that the following list of activities serve as a guideline in planning this effort:

Initiate development now:

Develop performance data and ATC automation tools to implement CDA on a wide basis with minimal degradation to capacity

Develop a noise benefits model that can be used to quantify the specific benefits realizable in actual terminal environments

Perform analysis, design, simulation, and flight-testing of FCS and FMS improvements in support of:

- Increased GS intercept altitude (Extended GS)
- Precision lateral navigation to short-final approach on standard ILS GS
- Two-segment approach to standard ILS GS

Follow with development of:

Air mass sensing technology requirements, and procedures development and simulations to implement:
- Delayed/reduced flaps procedures
- Delayed landing configuration procedures.

Develop enhanced airborne systems automation functions and ATC automation tools for implementing ACDA.

Development, simulation, flight testing and procedures development are required to implement two-segment-to-short-final approaches, and other complex approach procedures.

Promote development of GPS/LAAS as sole means for conducting precision approach procedures (independent of ILS GS). This requires extensive analysis, simulation, flight test, standards development, procedures development and demonstration. This technology would enable:
- Increased GS angle approaches
- Dual threshold approaches
- Optimized multi-threshold approaches.

Appendix A
List of Acronyms

3D	3 dimensional
4D	4 dimensional
AATT	Advanced Air Transportation Technology (Project)
A320	Airbus Industrie A-320 Aircraft
ACDA	Advanced Continuous Descent Approach
ADS-B	Automatic Dependent Surveillance-Broadcast
ANMAC	Aircraft Noise Monitoring Advisory Committee, UK Department of the Environment, Transport and the Regions
ANSP	Aviation Navigation and Satellite Programs, Inc.
ATC	Air Traffic Control
ATM/CNS	Air Traffic Management/Communications, Navigation, Surveillance
B727	Boeing 727 Aircraft
B737	Boeing 737 Aircraft
B747	Boeing 747 Aircraft
CAEP	Committee on Aviation Environmental Protection
CAS	Calibrated Air Speed
CASSTI	Chicago Airport System Strategic Technology Initiative
CAT	Category of Instrument Landing System
CDA	Continuous Descent Approach
CEC	Commission of the European Communities
CTAS	Center TRACON Automation System
CV-990	Convair 990 Aircraft
dB	Decibel
DGPS	Differential Global Positioning System
DME	Distance Measuring Equipment
DST	Decision Support Tool
EATMS	European Air Traffic Management System
EHGG	Grogingen Airport Code
FAA	Federal Aviation Administration
FAR	Federal Aviation Regulations
FCS	Flight Control System
FMS	Flight Management System
FRA	Frankfurt Airport, Germany
GARTEUR	Group for Aeronautical Research and Technology in Europe
GIS	Geographic Information System
GPS	Global Positioning System
GS	GS
IATA	International Air Transport Association
ICAO	International Civil Aviation Organization
IFR	Instrument Flight Rules
ILS	Instrument Landing System
IMC	Instrument Meteorological Conditions
ISTC	International Science and Technology Center
LAAS	Local Area Augmentation System

LP/LD	Low Power/Low Drag
MD-11	Boeing/McDonnell Douglas MD-11 Aircraft
MDW	Midway Airport code
MIT	Massachusetts Institute of Technology
MLS	Microwave Landing System
MSL	Mean Sea Level
NAS	National Airspace System
NASA	National Aeronautics and Space Administration
NLR	National Aerospace Laboratory, The Netherlands
nm	Nautical Mile
NWS	National Weather Service
ORD	Chicago O'Hare International Airport Code
R&D	Research & Development
RNAV	Area Navigation
SAIC	Science Applications International Corporation
SEATAC	Seattle/Tacoma Washington Airport Abbreviation
SEL	Sound Exposure Level
SOURDINE	The Study of Optimization procedURes for Decreasing the Impact of NoisE around airports
TMA	Terminal Movement Area
TO	Task Order
TRB	Transportation Research Board
U.S.	United States
UK	United Kingdom
VFR	Visual Flight Rules
VOR	Very High Frequency (VHF) Omnidirectional Radio Range

Appendix B
List of References

(References A-S are in order by date, oldest to most current, as found in Reference T "Literature Review")

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Appendix C

Application of New Navigation Technology to Noise Abatement

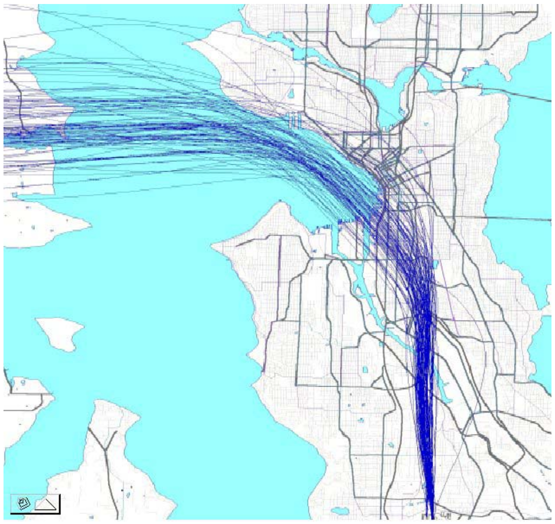
The Global Positioning System or GPS satellite array transmits signals that are accurate to 30 meters or less. Emerging technology will soon be augmenting the raw GPS signals to achieve much higher accuracy. The FAA is developing what is called the wide area augmentation system or WAAS, which is expected to produce signals accurate to around 10 meters, and there is a government industry partnership developing the local area augmentation system (LAAS), which will produce signals with sub-meter accuracy when implemented in the next few years.

The flight management system (FMS) is the cockpit system that integrates all the aircraft sensory data, including navigational data from all available sources. It also includes the flight management computer. The FMS can "couple" navigational data directly to the flight management computer, which in turn can fly the aircraft with precision in relation to waypoints in space. These existing and emerging navigation technologies can be effectively applied to noise issues as well as capacity and safety issues. This technology has the potential to significantly increase the capacity of an airport without adding or extending runways, since by knowing the location of each aircraft in the terminal airspace more precisely, separation standards can safely be reduced, thus increase the volume of simultaneous operations around any given airport. Current flight procedures are based on the accuracy of the present radar vectoring procedures and rely mostly on ground-based navigation equipment. The total current system error of the flight tracks is approximately 2nm. This can be reduced to about 0.3nm with FMS guidance and current navigational signals. FMS has the potential to eliminate rigid ground-based routes and voice communicated radar vectors and allows aircraft to fly any route programmed into the computer with a degree of positional accuracy that is not currently available with the ground-based equipment. The addition of GPS signals would further reduce the total flight track error to about 0.15nm. Currently, however, certain phases of flight can still not be accommodated by using just GPS. The ideal system is the differential GPS (DGPS) enhanced FMS computer guidance, which provides a total system error of only about 0.01nm. DGPS signals provide more precision instrument approach capabilities, therefore, reducing aircraft operational limitations during instrument meteorological conditions.

The capability of GPS-aided terminal area guidance, in terms of straight, curved, or segmented precision guidance (horizontal and vertical) implies new strategies for aircraft arrival and departure – not only precision approach guidance, but the same precision for departures and missed approaches, etc. Weather need not be the only critical factor in determining the types of navigational aids to which an airport subscribes. Land use compatibility considerations and noise abatement operational needs can and should influence the level of effort and schedule for transitioning toward satellite navigational systems. With carefully planned applications, it is possible to significantly reduce noise levels in some of the most sensitive areas surrounding airports. This can be achieved by developing high-resolution, predictable, repeatable noise abatement flight tracks over highways, railroads, rivers and other noise compatible land uses. The ability to channel a high volume of airplanes over publicly agreed upon ground tracks, accurate to within a few meters, is a noise abatement technical breakthrough comparable to the advent of higher bypass ratio jet engines.

High resolution, predictable and repeatable FMS flight tracks have been developed for noise abatement at several airports around the world, and more are being planned and developed. These curved noise abatement flight tracks can be flown accurately by FMS equipped aircraft, and the fleet percentage of FMS equipped aircraft is very high and will approach 100 percent on large transport-category aircraft in the next few years. As these aircraft become equipped in the near future to take advantage of WAAS and LAAS they will achieve the highest possible resolution noise abatement flight tracks with repeatability within a few meters throughout the terminal area. FMS prescribed area navigation (RNAV) techniques have been employed as noise and operational procedures for several years in the Federal Republic of Germany at the Frankfort International Airport, with other implementations underway or planned. The procedures were jointly developed and tested by the German civil aviation authority Deutsche Flugsicherung and Lufthansa, under the coordination of the Federal Republic of Germany Noise Abatement Coordination. The German project serves as a model for the DGPS-coupled FMS-RNAV procedure development between operators, airlines, and the FAA.

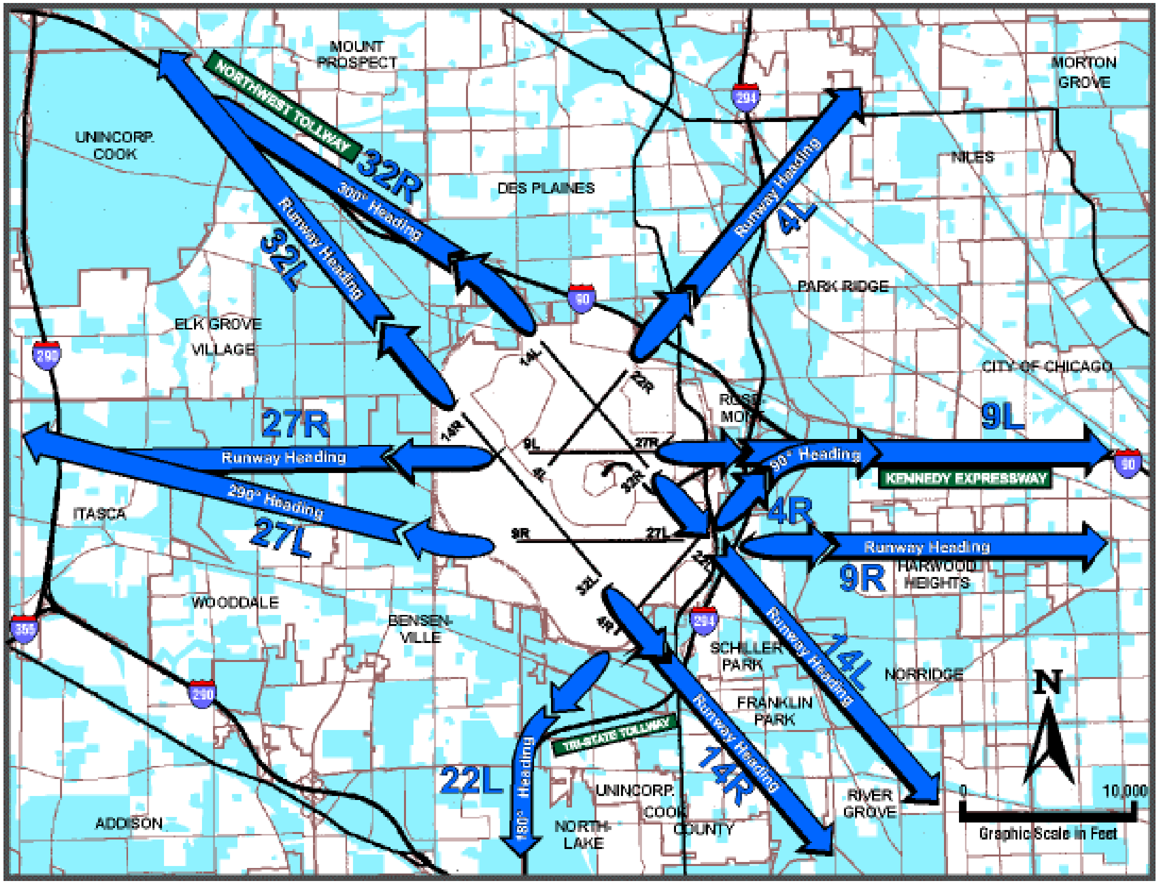
In the U.S. Seattle-Tacoma Airport and Alaska airlines developed an FMS noise abatement departure track, which has been certified by FAA. The comparison is displayed below. There are a few FMS-equipped B- 737s that obviously did not fly the FMS procedure. They may have been vectored by ATC for some reason, had equipment malfunction, or for some other reason not flown the FMS procedure. This clearly illustrates the current level of accuracy achievable in following a noise abatement flight track with FMS-equipped aircraft. When a LAAS station is fully operational at Seattle in a few years, and when most all of the airplanes are FMS-equipped, and assuming



Alaska Airlines MD80 aircraft- Departures from SEATAC to Alaska (non-FMS)

Alaska Airlines FMS-equipped 737s - Departures from SEATAC to Alaska operators couple up with the LAAS signal, the flight track resolution in these diagrams will improve to pencil line width.

Airlines at O'Hare International and Midway Airports have agreed to use designated noise abatement flight procedures under the Fly Quiet Program to further reduce the impact of aircraft noise. The Fly Quiet Program provides comprehensive guidance for pilots to use designated quiet flight and operating procedures developed by the Department of Aviation in cooperation with the O'Hare and Midway Noise Compatibility Commissions, the airlines, and air traffic controllers. The Chicago Department of Aviation distributes Fly Quiet Aviator's Manuals to airline pilots and air traffic controllers that contain information on preferred runways and flight tracks which route aircraft over the least populated areas -- such as forest preserves, highways, as well as



27L - Make Right turn heading 290° until 3,000 feet MSL.
14R - Fly runway heading until 3,000 feet MSL.
32L - Fly runway heading until 3,000 feet MSL.
9L - Fly runway heading until 3,000 feet MSL.
22L - Make left turn heading 180° until 3,000 feet MSL. (following the TriState Tollway).
4R - Fly runway heading for 1 mile then right turn heading 90° until 3,000 feet MSL (following the Kennedy Expressway).
32R - Make left turn heading 300° until 3,000 feet MSL (following the Northwest Tollway).
* All other runways - Fly runway heading until 3,000 feet MSL (4L, 9R, 14L, 22R, 27R).

commercial and industrial areas. The illustration above shows the fly quiet routes on which local and political agreement among the affected communities has been reached.

Since implementation of the Fly Quiet Program, there have been many complaints that airplanes are not following the agreed upon tracks. The airport recently retained Aviation Navigation and Satellite Programs, Inc. (ANSP) to develop FMS flight tracks that will yield the desired tracks shown in the diagram. ANSP is working closely with the airlines and the FAA to insure acceptance of the FMS procedures by both the operators and FAA, air traffic control.

United Airlines (Chicago Department of Aviation's partner in the LAAS Government/Industry Partnership) is testing the FMS procedures using flight simulators located at their United facilities in Denver. According to United Airlines senior pilot Tom Graff, in a Chicago Tribune news article on December 20, 2000, the FMS allows for the automated operation of aircraft navigation capabilities, thus, allowing for better accuracy along established flight routes and noise abatement flight tracks. The FMS will correct any deviation from the desired flight path hundreds of times during one-minute intervals reducing the change of drifting from the intended flight path. A set of waypoints consisting of a series of latitudes, longitudes, and altitudes are defined and put into the system. The computer relates this information to the aircraft's position as indicated by ground navigation equipment. The FMS will anticipate navigation errors and correct them according to on the difference between the ground-based navigational equipment's position and the inputted waypoints. The FMS, then, will plot the flight path accordingly. According to the simulation tests that have been performed by United Airlines the aircraft kept a consistent position over the desired nonresidential flight track, even under extreme weather conditions such as wind shear and 115 degree temperatures. The major ATC concern is that not all aircraft have the necessary technology to utilize the FMS procedures. However, according to the Air Transport Association, 80 percent of commercial aircraft in the U.S., mostly represented by major airlines and cargo carriers, possess FMS capabilities.